VAN NOSTRAND'S
ECLECTIC
ENGINEERING MAGAZINE.

No. LXIX.—SEPTEMBER, 1874.—Vol. XI.

A RECORD OF EXPERIMENTS, SHOWING THE CHARACTER AND POSITION OF NEUTRAL AXES, AS SEEN BY POLARIZED LIGHT.

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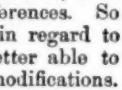
Transactions of the American Society of Civil Engineers.

Preliminary.—The experiments recorded in the following pages, were undertaken with a view to discover, whether the law of the "lamination of material in planes perpendicular to the direction of the pressure excited upon it," was a law incidental to a periodic* action of force, as pressure; or only consequent upon tangential stress, faults in the cohesion of material, or the running together of internal cells. The first of these was made by sending polarized light through plates of glass, compressed so as to be bi-refractive either in the character of beams or columns bearing weights.

As some exception may be taken to this apparently absurd means of obtaining the course of strains in materials used in construction, and because glass is itself a useless material for the sustaining of weights, it may be well that the experimenter's reasons for the proceeding should be given. The difference in effect between like action on two materials is not absolute, but only relative, therefore the effect of the action of force in glass must be similar to its effect upon other substances, excepting for amounts and confined qualities. One of these latter is transparency, but this becomes useful; and moreover, as the particular results which we wish to arrive at are derivable from certain general laws of the "doctrine of forces;" which must be precisely the same for all substances and only modified, not changed by any particular substance, and which the transparency of glass and its bi-refractive quality when strained enables us to watch with the eye of the body, in assistance to the eye of the mind; we may, in this partial case, completely ignore structural differences. So that, having become satisfied in regard to the general law, we may be better able to systematically admit the modifications. These modifications, indeed, would not appear to be very great. Glass, cast-iron and steel are all amorphous bodies, yet all composed of segregated crystals, and during the experiments a connection was established in the characteristic form of breakage; all as a general result appearing to yield in this form: when the fracture occurs in a beam between a supporting point and a point of pressure, and in this one when the fracture occurs immedi-

Fig. 1



* The word periodicy being used to express a re-occurring phenomenon without reference to the time occupied.

ately at a point of pressure: *Fig.* 2.

it being readily noticed that the law of fracture is the same in both cases; Fig. 2 being similar to Fig 1, with an opposite duplicature. Another and very important link of connection is believed by the writer to exist in the relative ratio of their respective resistances to tensile and compressive strains, as there is good reason to think that in this respect glass occupies a place between steel and cast-iron. These facts, however, become of less importance as we begin in the experiments to perceive the action of general laws, and to refer to their effects without regarding the vehicle which transmits them.

The form of apparatus used was the common one for experiments with polarized light, made without the microscope; namely, a bundle of glass plates—parts of window panes in this instance—6 by 8 inches. This was the polarizer, and one plate of heavy glass of the same size, blackened upon its back so as to reflect from only one surface was the analyzer. The first is set at an angle of 33° from the window through which the light is obtained, and the latter at an angle of 33° from the table upon which it is placed, or rather it is so placed that the rays of light reflected to it from the polarizer, come to the eye of the observer placed above at an angle of 57°. Between the polarizer and analyzer is held a small brass clamp used for compressing the object under examination. Looking into the analyzer, there is seen before compression, the clamp (a square frame of brass, with a thumb-screw moving from the top side towards the bottom) containing, in position, according to the experiment intended, a slip of glass, or a piece of glass tube or rod.

The glass appears clear and ordinary looking, because of the ordinary light which is present, but if our apparatus were so closed up on all sides as only to admit of the polarized rays, *it would appear black, for in a neutral or unstrained state, it is not permeable by those rays.* Yet even now, by close examination, we perceive a cloudiness.

Beams.—Supposing that our object is a beam, as *G* (see Plate), and we tighten the screw a little, immediately we obtain clear spaces with curved outlines at the top and bottom of the slip, while the darkness of the middle portion seems to increase. This dark space, in all its changes of form, marks by its outlines the neutral or unstrained sections of the beam. As it at first covered the unstrained beam, so it ever, by well-known optical laws, covers those portions of the beam remaining neutral or unstrained. Its increasing darkness, even, is only the effects of optical contrast; to pure polarized light it has always been black. Yet it does become more and more defined and distinct and narrower, as with the increasing pressure its outline becomes sharper. Soon, from the top and bottom of our beam, colored curves, each sharply distinct from the other, and having for their outlines the mathematical lines of strain, begin to make their appearance. As the pressure is more and more applied, they increase in number and brilliancy, moving always towards the neutral space. To a certain extent, there is a change of form, but the general curve is sustained until the period of fracture renders the image but a void of broken glass, the fractures of which may now be examined to obtain their position and character.

The images of *G* give a good idea of the results appearing in a beam, the ratio of whose depth to length is as 1 to 3.5, which rests upon two points of support, and which is pressed by a force partially local and partially distributed. The pictures opposite each other in the right and left-hand columns, are the positive and negative images of the same object in the same state.

The relative causes and properties of the positive and negative images, which together form each double picture, cannot easily be discussed until we have acquired, later in our experiments, a better knowledge of the character of the phenomena, after which, their great coöperative value will, doubtless, be admitted. They are, as arranged, images of the same state of the same object taken, first in one position, and then in another in the same plane, 45° distant, or by a revolution of the analyzer at each 90° distance. The words *positive* and *negative* are, of course, purely arbitrary, the negative image being the one occurring when the beam is horizontal and the column vertical.

The first matter which engaged attention and gave a definite course to the experiments, was the unsuspected and peculiar form and character of the neutral axis, and

systematic trials were shortly commenced to arrive at a full understanding of its status, under all circumstances of load and position. It will be remembered by engineers, that during the long, patient and able researches of Eaton Hodgkinson, F. R. S., published in 1842, he took the ground that the neutral axis was shifted by increasing the weights used, and, ultimately, that its position should be found at a line which would equalize the sum of the stretching and shortening forces, by a corresponding distribution of material above and below it. He fixed this line for cast-iron—at the period of rupture—one-seventh the depth of the beam from the top, because the resistance to compression of that material was seven times as much as the resistance to tension. He occasionally found rectangular beams, which broke, so that the broken edges exhibited a crushing force for one-seventh of their depth, while the tearing forces occupied the other six-sevenths, thus apparently corroborating his theory by an exact distribution of strains, in accordance with his previous experiments upon the compressive and tensile resistances of the material. Therefore, and most naturally, too, his whole argument makes it clear that he looked upon the neutral axis of the unloaded rectangular beam as a line at first coinciding with the longitudinal axis, but, which gradually rises towards the concave side at each accession of weight.

In 1855, Henry Barlow, F. R. S., made experiments upon cast-iron beams, purely to test this theory of Mr. Hodgkinson.* In the course of these experiments Mr. Barlow decides in direct contradiction to the views of Mr. Hodgkinson, that the neutral axis in a rectangular beam under all circumstances lays through the centre of gravity of the beam sections, and that there is a third element of strength consisting of the lateral adhesion of the fibres—"something like friction"—which increases with the curvature of deflection.

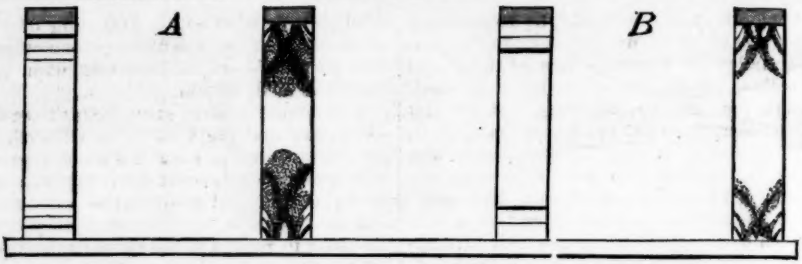
Both experimenters start from the same point, viz: that the transverse strength of a cast-iron beam is about 2.5 times as great as it would be to accord with experiments on its tensile and compressive strengths, and each records a different theory from the other in regard to the character and position of the neutral axis. This paper will show, that while both gentlemen were correct in the experiments made by them, these experiments were so diverse in character as to lead to two opposite theories by necessity, and by making a connection between the two sets of trials, also connect the observed phenomena and correct the theories. An attempt will be made to establish that the neutral axis is a flexible line, truly parallel to the top and bottom sides of the rectangular beam, and passing through the centres of gravity of its sections, only when the load is evenly distributed from end to end, or when the beam should be infinitely long; but that when there is a local pressure the neutral axis is more or less governed in its direction and form by the strain passing from the point of local pressure towards the points of support.

This mobile character of the neutral axis having been observed by the writer in his earlier trials, his first object when systematizing the further experiments was to obtain a law of direction, or rather to examine one already prevised. For this reason the negative image of column *A* was taken and recorded as evidently the simplest case that could be provided of direct compression. Then two slips of glass, *C*, were fastened in the press, so that when the pressure became heavy the two outside bottom corners should press against practically inflexible buttresses—the inside top corners press against each other—and the inside bottom corners and outside top corners of course be free. Thus there would be no tension in the beam, as a beam, and the compression could be governed by the screw until the coerced corners should be ground to powder. The image plainly represents two inclined columns like *A* each, or to speak more technically two "struts."

The simplest and most efficient way to conduct the experiment was obviously to make its different steps as closely consecutive as possible. The next object, there-

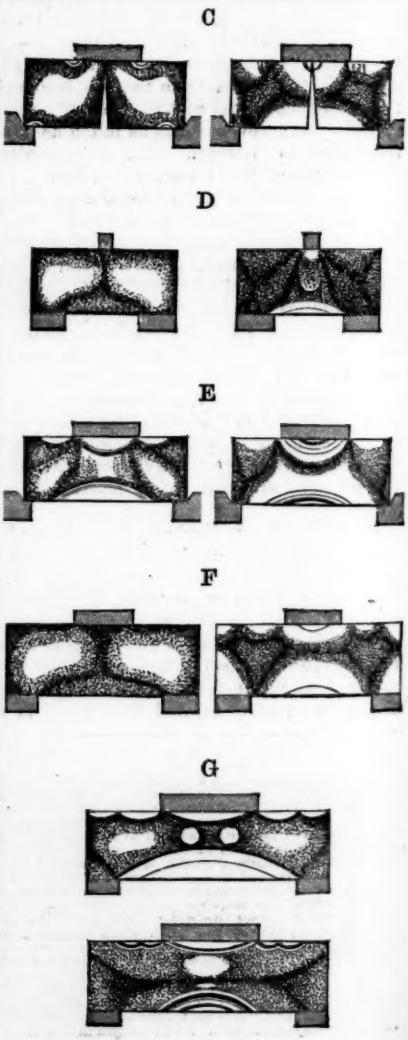
*He says: "It has long been known that under the existing theory of beams, which only recognizes two elements of strength, namely, the resistance to direct compression and extension, the strength of a bar of cast-iron, subjected to transverse strains, cannot be reconciled with the results obtained from experiments on direct tension, if the neutral axis is in the centre of the beam. The experiments made both on the tranverse and the direct tensile strength of the material have been so numerous and so carefully conducted as to admit of their accuracy, and it results from these either that the neutral axis must be at or above the top of the beam, or there must be some other cause for the strength exhibited by the beam when subjected to transverse pressure.

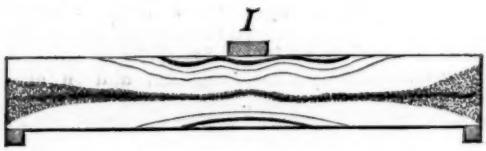
"In entering upon this question, it became necessary to establish clearly the position of the neutral axis, and the following experiments were commenced with that object, but they have led to others, which are also described herein, and which established the existence of a third, very important element of strength in beams."

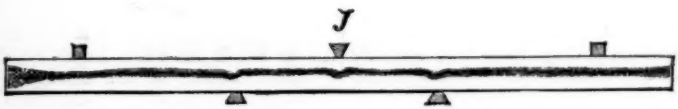


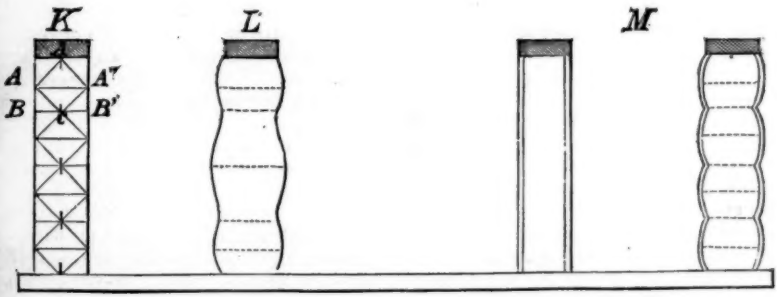
fore, should be to attain a very small tensile strain with a great preponderance of compression. D, which was the next subject of trial, was a very short slip in proportion to its depth, with points of support very close together, so as to allow of but little flexure, and pressed like the rest by the small leather guard of the screw. Passing across from the negative to the positive images for reasons to be hereafter given, a dark line surrounding a blue figure may be observed in *D*, as in the positive of *C*. Now, this blue figure is the complementary or positive appearance of the struts of negative *C* and *D*, and the dark surrounding line must, from the law mentioned in the first part of this paper, be neutral. In fact, the blue is in a state of semi-neutrality, shown by the small amount of the polarized light passed through it.

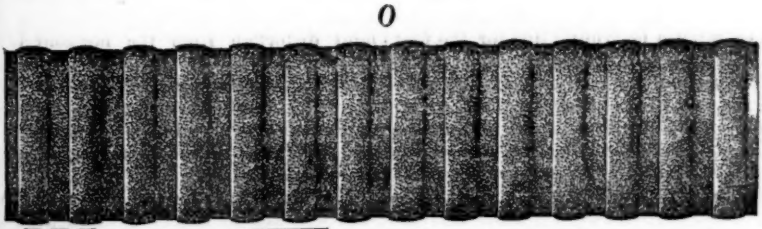
Confining the discussion to the neutral axis as it appears in the subsequent positive images, until experience shall have taught us the co-operative uses of both, let the beam which rests upon inclined but partially flexible supports be gradually lengthened in *E*. The blue is now less characteristically a strut, but the dark line still surrounds it. Only, however, on the side towards the middle of the beam is it plainly marked, and then not more so than in the new portion, which forms a curve extending from one corner of the "pressure block" to the other. The neutrality in this case, then, is in the narrow band running from one abutment in a curved line to the corner of the pressure block, from thence in a curve to the other corner of the same block, and from thence in a third curved line to the other abutment, and in two branches proceeding from the abutments toward the upper corners of the beam; the space between the first and third and the branches remaining, as it were semi-neutral. Looking backwards it will be perceived that the first and third lines, the branches and the











X-y-X $y = d\sqrt{\frac{R^2 + r^2}{2}}$

semi-neutral spaces result from the strut strains, formed by the direct compression from the pressure block towards the abutments, and we may begin to believe that the second line has been formed by the introduction of a distinct tensile strain along the lower part of the beam, creating with a horizontal compressive stress the bending moment which is just breaking in to complicate the strains. Simultaneously with this bending moment it will be perceived that colored curves appear upon the top and bottom of the beam. This beam, however, is far advanced towards the point of rupture.

F is a longer slip in proportion to its depth, but the local pressure still upon its centre. In this, the general neutral space is a broken curve or arch, from one abutment to another, only sending off cloudy branches, towards the upper corners of the beam, and the lower corners of the pressure block. This slip has, as yet, been little pressed, and the yellow color of the curves shows that they have but recently made their appearance. In *G* is shown the image of a beam upon the border of breakage, generally similar in character to *F*, but the beam being longer in proportion to its depth, the arch becomes much flattened; we still observe the running up of the neutral space towards the same points, and further notice that they inclose the colored curves in so doing, like the quiescent water which lies between opposite vortices.

H a, *H b*, is a beam with the load equally distributed. The "strut force" has disappeared from the top, and is only marked upon the beam, where, starting from the abutments, it becomes diffused about the centre, spreading, as might have been expected, when a local strain was changed to a general one, throughout the whole top of the beam. Undirected by a local pressure, it becomes undefined and cloudy, the neutral space belonging to the regular bending movement of the beam, detaching itself and becoming a horizontal line for the first time. The colored curves are regular and nearly equal on top and bottom, and with the exception of the "strut force" which appears in the negative at the abutments, and the complementary shading in the positive, there is no sign of local pressure. It may be noticed, too, how its colored curves are becoming more nearly similar in positive and negative images—how the colors are becoming more plainly complementary in the two images and how an umbra, which is a true neutral axis, surrounds the colored curves of the negative and connects them across the centre. Looking back, we may now perceive this neutral axis, in direction nearly perpendicular to the one in the positive image, has followed us up from the column to this point, and will beyond.

I is a long beam in the ratio of its depth, and we see clearly how its length, or rather its flexibility draws the neutral axis out into a nearly straight direction, parallel with the top and bottom edges; yet leaving perforce a slight upward tendency in the middle of its length due to the local force.

J is different in character from all the foregoing, and in attempt, represents a railroad bar pressed upon at one point, resting upon two cross ties, and prevented from rising by others, to which it is supposed to be spiked. Again the self-same laws prevail, the neutral space, in general horizontal, tends to bend itself toward each pressing point, and as in all the other images to brush out when free.

Those beams of Mr. Hodgkinson's by his own account, which plainly showed the neutral axis as being above the centre of gravity of the transverse sections of his beams, were *broken at the centre by a blow*. It was, therefore, as these drawings show, the local force and not the ratio of compressive and tensile resistances which governed its position. Mr. Barlow experimented with long beams, twice as long in proportion to the depth as any of those which appear here, and nearly 1.5 times as long as those mentioned by Mr. Hodgkinson in this connection. As the increase of the "bending movement," and the decrease of the "strut strain" keep pace with this lengthening of the beam in the ratio of its depth, he naturally found the neutral axis more nearly horizontal and less distorted than even in *I*. Beams of glass, with a ratio of 1 to 14, which is the proportion of those used by Mr. Barlow, show a very faint distortion from the horizontal and measuring as he did from points one foot distant from each other, this slight distortion might easily have escaped the scrutiny of his micrometer. Indeed it must be almost indefinite in beams having a ratio of more than 1 to 10.

May not it then be said of the neutrality as it appears by polarized light, that it is not a mere line in the mathematical sense of the word, but by reason of the cohesion

of material or other cause, is extended to a breadth, and can never become a true line until the tensile and compressive forces become in relation to the cohesion—infinite; or, in other words, that although the neutrality of "stress" is a mathematical line, yet as in material it must require a certain definite "stress" to produce a "strain," the initial "strain," namely, that sufficient to overcome cohesion must be at some distance from the mathematical line of neutrality. Beyond this it appears that its longitudinal diirection, like the directions of lines of strain, not an arbitrary one, but is resultant from the relative qualities and quantities of all the forces in the beam, its evident place in physics being precisely that of the still water between opposing eddies or vort'ces.*

Positive and Negative Images.—It will be noticed that as yet no cause has beeu discussed for the difference between the right and left-hand views in the plate—the positive and negative images. To understand these, it is necessary to know, generally, that polarized light differs from ordinary light, insomuch that instead of vibrating from a centre outward in all directions in the same transverse plane, the pulsations are confined to two directions which, when a completely polarized state is effected, are at right angles to each other. In this condition the pulsations in one direction are transmitted through certain substances, when the beam of light strikes them at particular angles, while the pulsations in the other are reflected, and *vice versa*. Secondly; if ordinary light, or either of these beams, are transmitted through a bi-refractive substance, there will be a division into two other beams at right angles to each other, and these falling upon an analyzing medium, properly arranged, will be either transmitted or reflected, according to the angle of their pulsations, so that the eye will be only able to discern the one reflected or the one transmitted. Thus the ordinary light coming through the window was polarized by falling upon the polarizer at an angle of 57°, one beam was transmitted, and, so far as we were concerned, wasted. The other reflected was made to pass through the object which, impervious to it in an unstrained state, became pervious and bi-refractive in a strained state, again dividing the one beam into two, at right angles to each other; the one of which is reflected to the eye from the surface of the analyzer, and the other transmitted through its face, but absorbed by the blackened back, until a revolution in part of the object changes the directions of pulsation and reverses the condition of the two rays.

When experiments were being made upon the first tubular bridges, it was found that a wave of "buckling" always followed an angle of 45°, from the top where the load was placed toward the bottom; even crossing the stiffners put in to retain this normal angle. This was similar in principle to what is here called a "strut strain." Evidently this would be impossible in equilibrium, unless there also existed a corresponding tensile strain at right angles. A resultant of these stresses in a beam would obviously be vertical. Again, it is known that the principal stress in an ordinary beam is the horizontal stress, composed of a compression in the top and a tension in the bottom, and that the resultant of these is parallel to them and is called generally the neutral axis. There are, therefore, two resultants at right angles to each other.

In the first section it was shown, that the true neutral axis of a beam was not necessarily the horizontal line, usually so called, but a line resultant from the actions of both the horizontal and strut stresses, which was derived from the fact that the neutral or unstrained part of the beam coincided with this form. In a beam loaded with a distributed load, or one which is very long in proportion to its depth, the strut stresses assume angles of 45°, as before shown in the case of the tubular bridges, become individually small in comparison with the horizontal or flange stresses, and the horizontal stresses govern the resultant almost entirely, but as the beam is shortened, so that the strut or web stresses between the load and abutments, obtain an ascendency over the flange stresses, then the strut stress interferes controllingly with the horizontal stress, and changes the direction of the resultant axis until in a column it becomes entirely vertical.

By a re-examination of the drawings it

* The neutral character of the dark bands is most plainly shown by working at an open window, where a large quantity of ordinary light is reflected from the polarizer. The neutral portions are pervious to ordinary light; and by this means a white speck set upon the polarizer may be made to pass across them, by a motion of the head, from one set of curves to the other, as a star passes across a clear belt of sky from cloud to cloud.

will appear that when the strut strains are in an ascendency over the horizontal strains, the negative images are by far the brightest, and although they afterward become duller—as the strut strains become relatively less—yet the preponderance of vertical stress is always evident in them. On the other hand, the instant a tensile stress was introduced, so as to oppose the compression or strut stress, and resolve the effect into horizontal or "flange" stress, the positive images became brighter, and continued so to grow *ceteris paribus* with the increase of the beam in length, and consequent relative increase of tensile and flange strains. Further, it should be remembered, that divers stresses may exist in the same piece of material, crossing each other, and probably being mutually neutralized at the crossing, but continuing on afterward as individual and intact as when first they met.

As the glass is pervious to polarized light, when strained, and impervious when unstrained, we can only regard the light parts as strained in proportion to their brightness, and the dark portions as unstrained or neutral; and as the strain is the cause of the bi-refraction, it follows that the latter must be governed by the laws which govern the former. Further, the resultant angles of the strains are rectangles, as are the angles of polarization, and as the strains change in character, so do the polar images change in correspondence. It follows, then, that the images are pictures of the strains.

But this may be examined in another manner. If all the light—except that which falls upon the polarizer—were dispensed with, the object seen by the eye without the intervention of the analyzer, would yield no appearance of color, but only white light. Now, all the stresses in a *beam*, when united, must be in equilibrium, hence the light which measures and was produced by them, should also be in equilibrium, or in other words, colorless when the two rays are united. From this is deduced that the positive and negative images are complementary in form and color.

Further, it may be fairly assumed, should these reasonings be correct, that if there is any one point in the object which is under no strain, whatsoever stresses be applied to the beam, that point must remain dark under all revolutions of the object or analyzer. Now, there is such a point in the centre of the beam, nearly in the middle of the primary neutral axis, and between the forks of the strut strains, and which, by laws already discussed, resolves itself into a space, and this dark space is always observable in the analyzer, forming a sort of nucleus, from which the changes from positive to negative and the reverse take place during the revolutions. It is obvious that this point marks the crossing of the resultant axes, the one formed by the "web" or strut strains, the other by the "flange" or horizontal strains, as before discussed.*

Colored Curves and Secondary Neutral Axes.—The appearance of the light around the neutral band is the first symptom of distortion in the positive image, but soon there appears upon the top and bottom edges faint segments of yellow. At the lower side this occupies a large portion of the distance between the points of support, but at the top it varies with the arrangement of the load, the chord to the segment having nearly the length of that part of the beam directly pressed by the load. If the load be uniformly distributed over the whole length of the beam, the segment is similar at top and bottom, but if this be local, say consisting of a block of hard sole leather as a guard to the screw, then the segment will have about the same length as the block, and two smaller segments, differing a little in form, will appear at the sides. Beyond these again bright curves appear, as though preparing for the formation of more colored segments; but the writer has never succeeded in bringing out more than three, with sufficient distinctness in the colors of the extra ones to be satisfied as to their character. It may not be amiss to remark here, that all the images and colors appearing were quite as distinct as the shades represented in the drawings.

As the pressure is increased, the yellow from both edges moves forward toward the neutral band, becoming soon a zone, and a segment of red succeeds. Both

*The writer will endeavor at a future time to present the concordance between the mechanical and optical phenomena, more in detail and with greater precision. For the present, relying mostly upon the success of the ultimate experiments to prove the law conceived to be true, he has preferred rather to suggest the line of argument than to closely follow it.

these continue to move forward with the increase until the red, too, becomes a zone and a segment of blue appears. This is the end of the first series, and we mark with interest that with the blue or between that and the red there came a dark mysterious line. Turning the screw continuously we force the yellow, red and blue to move forward, the blue becoming a zone, and bearing its dark line with it, which constantly grows darker, and yellow, red and blue again chase each other upon the field to form a second series. The second blue also has its dark line. So far I have found no glass to stand more pressure than this.

Let us now remember Mr. Barlow's words: "But they have led to others (experiments) which are also described herein, and which establish the existence of a third and very important element of strength in beams."

In loading a beam, it is probable that the pressing force first seeks to connect itself with, or as it were feels for the points of support; afterward the bending action commences. Now, suppose the load to be very small at first, and gradually to increase, there must be a time, for the new resistance can only exist, according to Mr. Barlow's experiments, after the beam is bent somewhat—when this resistance is only just equal to that portion of the moment of the compressive force (we are discussing, for simplicity, the top part of the beam), which is directly opposed to it, and which may therefore be called the bending stress. Taking the vertical section through the middle of the beam for the discussion, we may fairly suppose that this occurs just when the dark line between the first blue and red comes upon the glass. Mr. Barlow has shown that the new resistance or resistances increase as the beam is bent, but as we know that by the increase of load the beam is still further bent, we derive that the bending force increases faster. Therefore, if at first the bending resistance, multiplied by its minimum statical arm, was equal to the bending stress, multiplied by the distance from the neutral axis to the top of the beam as its maximum statical arm, which at equilibrium it must have been, it must at last be equal to the increased bending stress, multiplied by a shorter arm, itself being now multiplied by an increased length of arm, whose axis is at the top of the beam. The line of equal moment then between these two forces must have moved down in the interim nearer to the primary neutral axis, and must continue to move downwards toward this axis as the load is increased. This is exactly the action of the dark line in the blue, and its appearance, to one frequently engaged in examinations by polarized light, is that of a line of equal antagonistic forces—in other words, a neutral line.

In a first examination of this matter there seems to be something anomalous in the fact of a neutral axis existing amid distorting forces, of a line in the top part of a beam which is neutral, yet growing shorter, or in the bottom part and retain its neutrality while increasing in length. But it is not so; for if we should load a beam to bending, and then without changing the relative status of its flange strains, compress or stretch it bodily in length, we should have precisely the same phenomenon—a line which is a neutral line between two forces—yet increasing or decreasing in length by the operation of other forces acting independently of the first. There might be a modification of form besides the change in length, but there could be no cause for annihilation.

Further notice of the movement of this secondary neutral line (if we may call it so), toward the primary neutral line suggests that should the two come together, then, according to our former reasoning, the bending stress, multiplied by its smallest statical arm, would have become just equal to the bending resistance, multiplied by its longest possible statical arm (from the top of the beam to the neutral axis), and that any additional increase of the bending stress, however small, would bend the beam infinitely, because totally unopposed; or in other words, the beam would break. This reasoning was curiously confirmed in the following manner: while watching the consecutive phenomena occurring in several slips, set one upon another, thus forming a laminated beam, with a small hand microscope, all the slips, save one, suddenly broke. For some reason, perhaps from the elasticity of the broken glass, or perhaps the screw which had been shortened by the reaction of all the slips, began to recover its length when only resisted by one, the secondary axis continued to move forward, so that the observer, not having the screw to manage, could watch its movements at leisure. As it neared the pri-

mary axis, its curve began to take the form of a bow, the two quarters passing the middle in the direction of motion, and when very close, two loops were prominently advanced, first one and then the other. As the first touched the primary axis, a sharp "click" was heard, and fine fragments of glass flew like hail from the sudden rupture, which followed just at *that point*. Immediately the second loop touched, with precisely the same phenomena, when the vision was gone and only fragments of glass remained. It is to be regretted that the flying of the glass particles made it impossible to watch the movements of the secondary axis in the lower part of the beam, or either of the dark lines in the second blue, but closer preparation at another time, when the phenomena is looked for, may lead to interesting results.

COLUMNS.—The column appeared to us at first as incidental, taking a subordinate place in discussing the general laws of a compressed beam. We shall now see that its own phenomena are well worthy of deep study—that it resists pressure by strange geometric laws, and marshals its forces to oppose coercion from a vast depth of mathematical resource.

Although with glass, probably on account of its hardness in relation to the screw, it seemed impossible, before breakage, to obtain more than from 3 to 6 rings at either end, yet when a softer material, such as copal, was used, the column was wreathed in colored bands from top to bottom. Observe the dark band between the blue and red. Its position is invariable whenever these two colors come together, and from the first my suspicions were decided that it marked either an unstrained path in the column or a division of equal antagonistic forces. In fact, we must not regard the bands as horizontal strata, but rather as sections of oblique planes which follow the directions of stress. (See diametric sections *A* and *B*, which are the negative and positive images of the same object.)

It was with a view of assuring myself of the truth of these suspicions, that I one day asked permission to search through the store-room of the Illinois & St. Louis Bridge Company for corroborative phenomena. In this room were many objects, crippled and otherwise, which had been tested in the testing machine belonging to that company, and I was in hopes of finding in changes of form some assimilation to the arrangement of colors in the glass columns, and especially something to corroborate the neutral character of the dark line, as already provided. There was no want of testimony in any piece of the existence of a wave action in the pressure, but in the solid bars this was confined to a cone like flattening (upsetting) at either end, and a determined "bulging" in the middle for those compressed, which was reversed in those subjected to tension. It was common to steel, iron, wood and cement cylinders (see *L*). Attention, however, was soon concentrated upon the tubes, all of steel, which plainly exhibited a periodic wave apparently at regular distances from end to end. Not being prepared at the time to measure them carefully they were left for a future occasion.

Still further to test the matter upon material, which would yield form instead of color to the forces brought to bear upon it, arrangements were made by me for a change of experiment. Definite trials were made upon brass tubes .45 inches outside diameter, .35 inches inside diameter, and a length necessarily confined to about 1.5 inches by the small clamp used. These were compressed longitudinally by a screw until the form assumed was permanent. *M* gives an idea of their original and assumed appearance. These trials have been carried through some 12 or 15 tubes and the results subjected to measurment, the store-room of the Bridge Company was again visited, and a scale used to measure, as correctly as possible, the distance between the waves on the steel tubes. Then, with very little labor, the results were tabulated, and with not much more (since either the outside or inside diameter, or the radius of gyration, were almost obviously the base, and some oblique line proceeding from the axis of the tube outwards, as certainly the hypothenuse of a triangle of pressure) the following empyric expression was derived, which, so far as I can discover, will locate any wave in relation to another, the material of the tube being of course equally resistant from end to end. Measuring from ventral to ventral, we have when $x =$ distance, $R =$ outside radius, $r =$ inside radius, $a =$ constant quantity varying with the material alone and dependent upon the angle at which it most easily yields.

$$x = a\sqrt{\frac{R^2+r^2}{2}},$$

This formula seems for brass tubes to become, as nearly as could be discovered,

$$x = \tfrac{5}{6}\sqrt{\frac{R^2+r^2}{2}},$$

and for steel tubes,

$$x = \tfrac{3}{4}\sqrt{\frac{R^2+r^2}{2}},$$

a being equal to unity. The steel tubes measured, varied from 1.5 to 2 and 5 inches in outside diameter, the waves on the only one of the latter present being perceptible, but faint except at the ends, from 1 to 42 inches in length, and from .05 to .25 inches in thickness of wall. They were 9 in number.

It became now necessary to show some cause for these phenomenæ and to bring their relations with the colored rings in the glass column, and especially with the dark line between the blue and red, into closer connection. With this idea a theory already prevised in part from the colored rings was taken up, with what appears to the writer a successful issue, as follows.

We learn from Rankine's "Civil Engineering and Applied Mechanics," that "no tangential stress can exist as a simple stress, but must be accompanied by another stress upon another plane, and that these two stresses have a resultant, which becomes a maximum when they are equal, departing from each at an angle of 45°."

Let us then consider the condition of a solid or hollow column, pressed evenly over the top by a great load, and resting upon a flat surface at the bottom. Evidently the weight must exert a tangential stress upon the walls of the hollow column, or the edges of the ultimate particles of a solid one, and as the longitudinal section of the column is rectangular, we may look for the accompanying stress to be at right angles to it. Let us for convenience consider these stresses to be equal, their resultant will have a direction between them and 45° distant, and if K represent the column, $A\,A'$ and $A\,A''$ will represent the resultants of the stresses. But these resultants act to push the material outwards at A' and A'', and as their action is, therefore, tangential or distortng, there results from our first law, and directly from this effect, two other "accompanying" stresses, C, A' and C, A'', which tend to draw the material atoms from C towards A' and A''. Now, where these stresses interfere at $A'\,A''$, they mutually neutralize each the vertical component of the other, so that there only remains at $A'\,A''$ horizontal forces, and where they interfere at C, they mutually neutralize, each the horizontal component of the other, so that there only remains at C the vertical component, equal to the weight at A, with which we commenced this discussion, and the plane B, B', is precisely in like condition as regards stress to the plane at A. It follows as a corollary that like conditions below B, B', will produce like results to those at A, and B, B', and so on for any number of equal divisions or periods, and it also follows that such planes as A and B, B', etc., are unstrained by horizontal forces, and should, therefore, appear dark in the positive image, and that such planes as $A'\,A''$, etc, are unstrained by the vertical forces, and should, therefore, be dark in the negative image, which, in the bi-refractive glass columns, under polarized light, we find to be true, while in the metal tubes compressed we find a concording form.

L shows the form of the wave assumed by thin brass tubes—probably any thin tube—which has for its periods the same formula as the thicker ones, but differs in the vertical fold, and the consequent interlaced triangular section. It is probable that the vertical fold does not occur from any definite change, but only from a modification of our law, and may rather be regarded as a buttress, thrown out by tubes of a certain thinness, to resist transverse bending, and from thence propagated, by the natural pulling of the force of its creation, upon straight lines, and located by the well known properties of the equilateral triangle as a perfect figure of equilibrium. Its position in the succeeding period midway between those formed above it, so that one triangle interlaces with and bisects the other, may also be accounted for by the fact that the middle of the side of the triangle is its weakest point, and the new buttresses are thrown out there in consequence of greater yielding at that place.

Remarks on Attendant Phenomenæ.—It was apparent during the course of these experiments on columns that each piece of material was mechanically polar, or, in other words, had a favorite end. This was shown in glass and brass by the end against which the screw-plate worked,

yielding first. In the thick tubes, and in transparent columns, this was followed by the other end, and in the same tubes, and in softer transparent material than glass, by the intermediate ventral points. Of course, after a certain yielding in glass columns, the balance of compression was against the brass screws, which then yielded more in this direction than the glass, the glass column ultimately giving way by splitting down perpendicularly, as all vitreous substances naturally do, except a transverse crushing where the rings had appeared, making a nearly cubical fracture. In thin tubes the waves formed from the screw or active end towards the other end consecutively.

When, as frequently occurred, the tubes were not of exact length to make a regular succession of equal waves, then the difference was invariably made upon the base or passive end by a half wave longer or shorter than the normal half wave shown at each end in the drawings. In only one case was an abnormal wave noticed, this in a brass tube with an evident soft place in the material, which divided into five waves in the usual space for four, one wave coming within the soft place.

In the proposition it will be noticed that the lines $A\,A'$, $A\,A''$, $C\,A'$ and $C\,A''$ are straight. This was only the natural result of an attempt to investigate forces proceeding from one point to another. Subsequent experiments, which have not been as yet sufficiently wrought to publish, lead me to regard these as curved lines, and to consider the figure $A\,A'$, $C\,A''$ as approaching an ellipse corresponding to the rhombus shown. The figures in the lower divisions would then, of course, suffer the same change from the same law.

I have thought if large, hollow columns yielded under the same law, and it should appear as apparent from the proposition and from other facts, that the law governs before the limit of elasticity was reached, then by reinforcing columns by bands shrunk on at the places pointed out by formulæ, we might greatly strengthen them at a small expense for additional material in the shape of rings (See *O*).

In conclusion, it seems to me, subject to higher decision, that the law of the periodicity of force in pressures, and probably in tension, has been fully proved in this paper, which will assist in accounting for the effects of re-occurrent applications of force and for the law of lamination under pressure, in planes perpendicular to the direction of pressure.

Mr. Charles Macdonald.—The experiments upon which formulæ in common use, for the proportion and strength of beams, are based, were made upon cubes of the materials tested; and it is found that the constants derived are inapplicable to ordinary cases in practice. It is known that a beam, loaded so that its outer fibres by formula should be under maximum strain, will stand a greater load. The constants employed in calculating the strength of a beam should be determined from experiments upon a similar beam of the same material, and not those given for direct tension and compression.

Mr. Alfred P. Boller.—A recent comparison of various standard formulæ for the strength of beams, made by taking a given beam and calculating, with each formula, its safe load, gave as follows:—two, 25 tons; one, 30 tons; and one 37 tons. The last was from Mr. Baker's formula, in which he has introduced the resistance due to flexion. The beam taken was 3 by 6 inches, and 5 feet long. Engineers should know more of the strength of materials. The formulæ used involve the application of constants ranging variously from maximum to minimum strength. These often differ widely, and, therefore, give uncertain results.

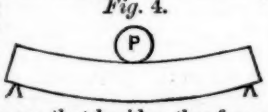
Prof. De Volson Wood.—The point of greatest interest to me in the paper read, is whether the neutral axis is a line, or a space as water in an eddy. In regard to the neutral axis and strength of beams, as determined by ordinary rules, the fact is, if we assume in a bent beam that the extensions and compressions are proportional to the distance of the elements from the neutral axis, and take the modulus of tenacity or of crushing, as the case may be, for the modulus of rupture of the beam, a beam proportioned in accordance therewith will have an excess of strength. To illustrate this, take the case of cast-iron, which is the best example in practice—the mean tensile strength (T) of cast-iron is 16,000 pounds, and the mean crushing strength (C) is 100,000 pounds, or, for convenience, six times as great as the other—96,000 pounds. If the beam is rectangular, supported at its ends and loaded in the middle, we have the well known formula:—

$$\tfrac{1}{4}\,P\,l = \tfrac{1}{6}\,R\,b\,d^{2}$$

in which P is the weight, l the length of the beam, b its breadth, d its depth, and R the modulus of rupture. According to this theory, the value of R should be 16,000 pounds, but according to experiments it is found that the mean value of R for cast-iron rectangular beams is about 36,000 pounds Former writers do not explain this discrepancy, but simply admit a defect in the theory, and pass it over by saying that a proper co-efficient of safety will make the formula a safe one. Barlow detected a new element of strength, which he called "resistance to flexure," a term which is unfortunate, as all the forces in a beam which resist bending, are resistences to flexure; "longitudinal shearing resistance" is a beter term, and one now used. This force is the resistance of the fibres to being drawn over each other. If there were no such resistance the fibres would retain their original length. To illustrate, suppose that several very thin but perfectly smooth boards of equal lengths were placed above each other, and supported at the ends. If now the pile of boards is bent, all the boards will retain their original length, and the ends will set past each other, as shown in Fig. 3, but the general range of the ends will be parallel to each other. If we suppose that there is friction between the surfaces of the successive boards, the upper ones will necessarily be shortened, and the lower ones elongated. In a beam, the consecutive elements are united by cohesion, and Barlow found by a critical examination of those of cast and wrought-iron, that the transverse sections remained normal to the neutral axis during flexure, and in this case the ends will not be parallel, as seen in Fig. 4. This being so, and bearing in mind the analogy between this case and that of the thin boards, we see that besides the forces which produce direct elongation and compression, there is a force between the consecutive elements somewhat analogous to friction:—this is longitudinal shearing resistance. Barlow found the laws which govern this resistance at the point of rupture, and modified the formulæ accordingly. The mode of his investigation and his results are fully described in the "Civil Engineer and Architects Journal," Vols. XIX and XXI. I consider them the most weighty and valuable sets of experiments that have ever been made upon beams, so far as theory is concerned.

Fig. 3.

Fig. 4.



It is evident, the ordinary law that the strains vary as their distance from the neutral axis can not apply to I sections, for to secure such action there must be at least a continuity between all the elements of the flange and those at the natural axis. Barlow made his formulæ applicable to this case, but it is equally evident that they cannot be rigidly correct. In all flange sections there is a peculiar combination of the strains about the angles where the flanges join the web, and it seems impossible to assign the laws which govern them.

Prof. Norton, of Yale College, determined from direct experiment, the fact of a transverse shearing resistance in beams, and also the laws which govern it for rectangular beams. His article was published in the "Journal of Arts and Science" and in "Van Nostrand's Eclectic Engineering Magazine." I had detected the same analytically. If transverse elasticity only existed in a beam it would be deflected. To show this by a figure,—suppose that short portions of the beam were perfectly non-elastic, and that between these were elastic sections. Then will a beam which is supported at its ends, and loaded at the middle be deflected, as in Fig. 5. If the beam has a continuous tranverse elasticity, it becomes evident that the deflection will be as shown in Fig. 6. The deflection due to this cause is additional to that due to Navier's theory, while longitudinal elastic shearing resistance will diminish it.

Fig. 5.

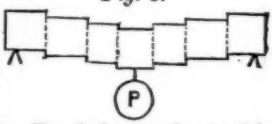
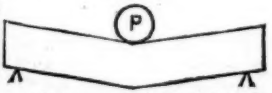


Fig. 6.



It is worthy of note that the strength of beams, as determined from Barlow's new formulæ and constants, agrees remarkably well with the actual strength for all the forms which he used. It is hardly to be expected that a simple law, or laws, can be given which will be applicable to all the forms of beams now used in practice. The constants which are determined from solid rectangular beams will doubtless apply

practically to solid beams of all dimensions, but not to other forms. For instance, if solid cast-iron beams give R=36,000 pounds, it will not be safe to use this value for hollow beams, or I beams. For such beams T=16,000 pounds is safe, but may give an excess of strength.

Mr. Boller.—It is best to make a beam proportioned similar to those to be used. Break it and deduce therefrom a constant. The formulæ for I beams are safer for thin than thick webs—say ¼-inch web and 4-inch flange.

Prof. Wood.—The experiments of Baron Von Weber, "Engineering," 1870, showed that the web had never been made too thin. Where the flange and web are joined there should be a large curve.

Mr. Macdonald.—In T. C. Clarke's description of the Quincy Bridge, there is a statement that 12-inch I floor beams, 15½ feet long, suspended in pairs from panel points about 12 feet apart, and carrying a single track of 4 feet 8½ inches gauge, scarcely deflected under a maximum engine load, which caused a strain upon the outer fibres at least equal to 14,000 pounds per square inch, according to formulæ in general use.

Prof. Wood.—We should not proportion structures in reference to the ultimate strength of the parts, but in reference to their elastic limits. The elasticity of the material should not be damaged. Some irons which are very tenacious have a low limit of elasticity, while others, and especially certain grades of steel, seem to preserve their elasticity for a strain nearly equal to half their tensible strength. Capt. Eads, in the construction of the St. Louis bridge, insists upon preserving the elasticity of the steel, and very careful experiments are made to determine its elastic limit.

Col. W. E. Merrill.—I regret I cannot give this as thorough an examination as I could wish. It opens a field for investigation that promises the most useful results in a matter of vital interest to Engineers and Architects, and in fact to every one; the laws of the action of strains on materials used in construction, and the proper method of meeting and sustaining them with assured safety. Being quite unfamiliar with the use and laws of polarized light, I do not feel competent to discuss the very interesting results obtained, but the method chosen, and the means pursued, seem most admirable. The plan of using glass to find out the laws of steel and iron, reminds me of the practice of physicians in ancient times of determining the laws of the human boby by experiments upon inferior animals. The limitations of sense having apparently put an insuperable barrier to the examination of the interior of opaque bodies under strains, the method by analogy seems the sole one that is open to us, aided of course by what we can see on the surface, and detect after fracture.

I have often thought it desirable to be able to see exactly how the strains in the different members of a truss bridge were working during different positions of the moving load. The method of Mr. Nickerson seems to offer that long-needed means. Further experiments will, probably, enable the experimenters to decide with fair accuracy upon the magnitude of an unknown strain on a glass column, by comparison with the observed effects of a known strain upon a similar column. I would suggest that a model of a Howe truss bridge be made with glass members and metallic joints, so constructed as to permit the ready insertion or removal of glass columns, acting as struts, ties, and chord segments. I believe that such a model can be made and so adjusted that broken parts can easily be replaced. If then the method with polarized light be used, valuable information about points now somewhat obscure could be obtained so as to command universal credence.

The proposed strengthening of tubes by external rings, at regular intervals, is a very curious result of the experiments, and if confirmed by practice, will be a valuable discovery. The whole discussion illustrates most admirably the inter-dependence of all branches of physical science, and the absurdity of considering any discovery useless, no matter how far it is apparently removed from a possibility of practical application in the useful arts. Hitherto the polarization of light has seemed a curious and occult phenomenon, of no particular utility, and only interesting to the man of abstract science, and here it suddenly springs up as a trustworthy means of unveiling the secrets of nature, and promises as great a future of discovery as the spectroscope.

Hon. William J. McAlpine.—As a practical question, the Civil Engineer has almost never to deal with glass as a material of strength, but it must be evident to all,

that it will be affected in the same way as any other material of similar construction, and hence that the effects of strains upon glass will be similar to those upon cast iron. At least the experiments made with such apparent care would be of great value in determining the law upon the subject.

It is a singular characteristic of this age that every discovery in science is made applicable to the service of our profession. Five years ago Prof. Airey (the Astronomer Royal) gave a paper on a new system of calculating the strains on each member of a truss, by a model in steel, which he had exactly duplicated. When the model bridge was loaded in all of the various ways, each member was struck, and the corresponding duplicate was loaded gradually until the two were in accord. The load on the duplicate indicated the strain on the corresponding member of the truss in position and under its load or strain. There we had *sound* to determine a most important engineering question; and now we have *light* in one of its forms of action.

Gen. J. G. Barnard.—I have been unable to give the matters presented by Mr. Nickerson the study required for a full appreciation. I would remark, however, that the peculiar circumstances under which the experiments for the neutral line or axis are made, are really foreign to the subject of the position of that axis as it is presented to the engineer in connection with the theory of the strength and stress of beams. That theory and the formulæ deduced, are like nearly all our mechanical theories of the properties of matter based on somewhat rude assumptions. Moreover, the formulæ for "beams" really suppose the length to very great, compared with the depth—practically infinite. No one supposes that, in pieces so short as the glass specimens experimented upon, the "strains," "stresses" and "strength" would be represented by the usual formulæ for "beams." That theory ignores all "strains," in the technical sense of the term, except those due to the elongation of fibre on one side of the neutral axis, and its forced contraction on the other. It is far from being a true exposition of the phenomena which are developed by the bending of a beam. The truth is limited by the imperfection of elasticity, and by any amount of deflection given to the beam beyond a very limited and exceedingly small amount; for tangential (or shearing) strains are disregarded.

The experiments upon pieces so short as those used by Mr. Nickerson develop phenomena which scarcely belong to the theory of beams, or to the position of the "neutral axis" in the usual acceptation of the term. I do not, in saying this, depreciate the value of experiments of that kind. They are directly applicable to the illustration of the strains produced in columns—and in all pieces subject to similar stresses I would remark, too, that glass, to the extent to which it is capable of receiving change of form without rupture, is almost perfectly elastic. Iron is far from being so, at least beyond the narrow limit to which it may be distorted without "set."

I am not familiar with the investigations of Mr. Barlow, but if the stress in a bent cast-iron beam be a "uniformly varying" one, he must prove, I think, that the co-efficient of elasticity is constant for all degrees of extension. That co-efficient for wrought iron varies in a table given by Morin (taken from Hodgkinson) to an extraordinary degree; being for extreme extensions, only about $\frac{1}{22}$ of its value for very small extensions; though within limits of practical strains—say to about 18,000 pounds per square inch, the variation is small, say $\frac{16}{22}$ of its maximum. For cast-iron the co-efficient for extension exhibits some variation also, in practical limits of stress, that is within limits of safety. For compression, both of cast and wrought iron, the co-efficient is (within practical limits say up to 15,000 or 18,000 pounds per square inch) more nearly constant in both materials.

In the experiments* made by me on the strain and rupture of beams of forged and cast-iron (of dimensions never before experimented upon, I believe), the co-efficient of elasticity as deduced, from the assumption of a "uniform varying stress" in the cross section, and a central neutral axis, varies in one of the forged specimens from 1,482,000 to 9,558,600 pounds per square inch—the smaller co-efficient corresponding to the extraordinary extension of fibre of .0463 and a "tensile strength" of 68,450 pounds per square inch—calculated from the amount of deflection of the beam)—and this extraordinary extension and this high tensile strength is exhibited in the iron of a *heavy forging*—*i.e.* in a forged beam, 15 by 12 inches in rectangular section. On the other hand, a cast-iron beam of the same dimensions, rupturing under a force

* Transactions XIV.

of 276 tons with a flexure of $\frac{3}{4}$-inch (the supports being 77 inches apart), exhibited a (calculated) extension of fibre of .00573* and a co-efficient of elasticity of about 40,000,000 pounds per square inch; and at the lesser flexure of $\frac{1}{4}$ inch (the only other observed), the co-efficient was about the same.

The variation of the co-efficient of elasticity under different degrees of extension, seems to me to be proof positive that in a bent beam there cannot be "uniformly varying stress" for while the extension of fibre varies, as it must do, nearly uniformly from the neutral axis to the exterior, the co-efficient of elasticity, the constancy of which is essential to a corresponding uniformly varying stress, is, in wrought iron, far from being constant. The co-efficients for cast-iron vary much less than for wrought iron—and indeed, my experiment just cited, with a cast-iron beam while developing an "extension" of .00573, which is nearly four times as great as the maximum extension in the table of Hodgkinson's results, given by Morin† .00155, indicate at that extreme extension the same co-efficient nearly, as for the less extension of .00382. Hodgkinson (as quoted by Morin) gives almost identical co-efficients of elasticity for cast-iron for compression as for extension: hence it may be presumed that the same is the case in the cast-iron beam ruptured by me.

There is, therefore, in this important experiment—the largest beam, I believe, ever ruptured experimentally—some confirmation that, for cast-iron Barlow's theory is true, viz.: that the stress in the cross section *is* a uniformly varying one, and that the neutral axis "transverses the centre of gravity." Yet from this experiment we deduce a discrepancy between the "modulus of rupture" and the "tensile strength" of the iron, even greater than for the case of the wrought iron beam in which enormous variation in the co-efficient of elasticity is clearly shown. The modulus of rupture for the 12 by 15 inches cast-iron beams would be, in one case, nearly double—in the other about 1.5 times the "tensile strength."

Mr. Barlow is probably right in the opinion (as stated by Rankine), "that the curvature of the layers of the beam produces a peculiar kind of resistance to bending, distinct from that which arises rom direct elasticity." It is evident that the theory of a horizontal neutral axis, however convenient, cannot be a true representation of the phenomena of the resistances developed in bending a beam.

Let us suppose the solid rectangular beam *A*, *B*, *C*, *D*, Fig. 7, resting upon supports at extremities to be bent to a *given deflection* by a force *P* applied at the middle. The neutral axis along the middle (according to theory) would be the line *m n*, and moreover the entire horizontal section *m n*, is in a rectangular section (or other symmetrical section above and below this plane), reckoned as neutral. But it is evident that it cannot be strictly so — evident that to stresses transmitted across it the three-fourth's computed resistance to flexure is due. For, let the beam be split along the section now, it will become two beams, of which the contiguous surfaces *m n* will slide over each other, and, the flexure being maintained the same, the two halves will appear as in Fig. 8, and the force to produce the flexure will be but $\frac{P}{4}$. There cannot, then, be a neutral line or plane along *m n*, and it may be doubted whether there can be really neutral lines or planes *anywhere* in a bent beam.

Fig. 7.

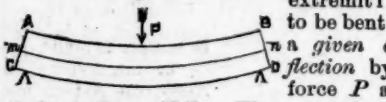
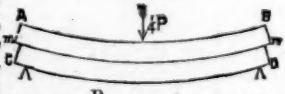


Fig. 8.



Researches with a perfectly elastic material, as glass, and one, too, which can be made to reveal to the eye indications of its internal strains, cannot but throw light upon one of the most difficult problems in mechanics, viz.: the internal strains of solids subjected to the action of external or internal forces. The general problem can be stated mathematically; but the analytical solution, except for a few simple cases, defies mathematicians. That portion of Mr. Nickerson's researches concerning the strains in hollow columns is very interesting, and I am inclined to regard his views on the "periodic" character of the strain, and upon the means of counteracting it, as well founded.

Mr. E. A. Fuertes.—Some time ago I noticed a flare or wing-like streak of

* On page 5 of the paper referred to, there are errors in the printing of the figures for the "extension of fibre." They should be .00382 and .00573.

† "Resistance des Materiaux," Morin.—1855.

light when examining the image of a star through my equatorial telescope. Fearful of some accident having taken place and impaired the object glass, and not being willing to remove it from its cell, I held in front of it a spirit lamp, on the wick of which I had poured some common salt. I at once observed the formation of Newton's rings on the lenses, but near the edge of the cell holding the lenses, the rings, instead of being concentric were scalloped, or bent inward toward their centre. Remembering experiments made by Pasteur, upon the pressure of mercury over a thin glass surface, I further examined the cell, and found that the disturbance of Newton's rings occurred near one of the screws which held the cell on the barrel of the telescope. I loosened the screw, and, to my great and natural delight, the interference suddenly disappeared. It was then evident that the cell had contracted through cold since the time at which it was screwed in the telescope, and that the pressure produced by this contraction caused the imperfection of the image, the location and extent of which was revealed by the soda light.

GEN. T. G. ELLIS.—Several years ago I gave much thought to the subject of strains in beams, and regretted that those who had given their attention to experimenting, had pursued their investigations in so unscientific a manner. Mr. Nickerson's examinations are a step in the right direction, although I do not see that he has developed much more than has heretofore been done by Wertheim of Paris, who invented an instrument for the determination of strains and pressures by the colors of polarized light. Prof. Tyndall has also done the same. I sincerely hope that Mr. Nickerson will pursue the matter further. What we want to know is the elastic resistance to tension and compression in any one substance, as glass, and the effect of a weight upon a beam of the same substance. Then, knowing by experiment the elastic resistance in both directions of other substances, we might reason with some hope of success upon the position of the neutral axis of beams of different substances In my opinion a great error of writers on the strength of beams is, in assuming that equal strains will elongate and compress the same substance to an equal amount, thereby making the neutral axis of the horizontal strains in the middle of a rectangular beam; also in assuming that the elastic resistances are proportional to the ultimate resistances of the material.

One part of Mr. Nickerson's experiments that I do not clearly understand, is, how polarized light can show a neutral axis in a glass beam supported at the ends with a weight in the middle. It seems to me that it should show only a neutral *point* in the middle of the beam, under the weight. There are diagonal strains in all parts of the beam except this central point, and diagonal strains should transmit the polarized rays as well as the horizontal ones. That there are diagonal strains in all parts of the beam, although they may be very small in the upper end corners, may be shown by supposing the whole to be divided into very thin horizontal laminæ. The flexure of the beams by the weight would then cause all of these to slip one upon the other. This is resisted in the solid beam by the diagonal resistance of the material. The additional element of strength referred to in the paper, is, I apprehend, not due to the absolute resistance of the material to the sliding of the laminæ upon each other, or the "horizontal shearing strength" as it has been called, but to the elastic yielding of the fibres of the material, which, without diminishing their ultimate strength, allows them to slip, so to speak, upon the next interior fibre, so that the latter are drawn to a greater tension, or subjected to a greater degree of compression than they would be if there were no such lateral elasticity between the fibres. The outer ones would be ruptured as soon as their limit of elasticity was reached, and before a full strain was brought upon any of the interior fibres, were it not for this action.

GEN. J. G. BARNARD.—I am disposed to think Barlow's position untenable, that the neutral axis *cannot* be in the centre of gravity, when the breaking strain is in excess of the result given by formula founded on that assumption. There is no more radical law of mechanics, than that the forces across any section must be in equilibrium. Take a cross section of a beam, and these forces cannot be in equilibrium if the neutral line is through the centre of gravity when the breaking force is found to exceed that due to tensile strength of the iron.

HYDRAULICS OF GREAT RIVERS.*

Condensed from the "Edinburgh Review."

It would be difficult to point out any part of the world, in which it is of more importance that the laws which regulate the flow and escape of water should be thoroughly understood than in Great Britian. The question comes practically home to us all. In our stormy and uncertain climate, the very aspect of our architecture betrays the fact that protection from rain and snow is one of the first objects of the builder. On the capricious character of our rainfall, the growth and the ingathering of our crops primarily depend. The course of commerce, filling with its wealth our noble and numerous harbors, is intimately dependent on the hydrographical advantages which they afford. For a large area of fen district in the Eastern Counties, man yet maintains a struggle with the sea, and with the land floods, hardly less precarious than that which has so long taxed the resolution of the sturdy Dutch. For the comfort of our homes, for the yield of our harvest, for the supply of our towns and cities with a prime necessary of life, and for the security of our commerce, we depend on the hydraulic skill of our engineers.

We shall be safe, at all events, in assuming the position, that it is highly essential that hydraulics should be thoroughly understood in this country. The question, how far this is actually the case, is, however, altogether different. It is one to which a reply is, manifestly, important. But that reply should not be lightly hazarded. It is one as to which it is worth while to take some degree of trouble, in order to arrive at certitude. Our health, our comfort, our prosperity; the amelioration of our climate; the yield of our agriculture; the facilities for our manufactures; the requirements of our commerce; are all so intimately dependent on a thorough knowledge of hydraulic law, as well as of hydraulic practice, on the part of our engineers and architects, that the question whether our command of the subject is really the best attainable by the human mind, is one of great interest to us all.

We have good grounds for forming the opinion that the laws of hydraulic action are far from being thus thoroughly understood, even by the professional and scientific men of England. We may be challenged, as we are of course aware, for a scientific justification of this doubt. But before entering into an inquiry that may tend to become somewhat technical in its nature, we will offer a reason why, at the first glance, it is not unlikely that our knowledge is imperfect.

In all natural science there exists a broad distinction between phenomena of a delicate and exact nature, that may be made the subject of careful experiment; and phenomena on a scale of magnitude and grandeur that can be the object of observation alone. We may weigh, to the fraction of a grain, the water absorbed by a plant; we can only look on with awe at a sudden inrush of a great tidal wave. To a certain extent all our physical knowledge is experimental. However searching and comprehensive may be the action of physical force (as in the simplest and sublimest case, that of the great force of Gravity), careful experiment is a necessary preliminary to the determination of the uncontrolled applicability of that force in each instance. It is only when we obtain mathematical proof, that we are justified in ascribing the course of phenomena to the sole action of any great primary law.

Now when the laws investigated are of great magnitude, and of corresponding simplicity, much inconvenience may result from drawing inferences from experiments made on a scale that is comparatively small. It is far safer to reduce than to enlarge. From good observations, in cases where bulk, weight, and velocity are all very high (as in the movement of the planetary bodies), we may deduce rules applicable to cases of minor magnitude and movement, with much greater accuracy and safety than can be attained by the reversal of the process. It is far safer to predict the course of a small stream, or the effect of a small tide, from observations of a great river or a rapid sea, than it is to estimate the movements of the Atlantic from observations of the Mediterranean, or to gauge the flow of the Plata according to our experience of the Thames.

It is precisely here that the matter is brought home to our notice. M. Révy, a

* The Paraná, the Uruguay, and the La Plata Estuaries. By J. J. Revy. London: 1874.

member of the Institute of Civil Engineers of Vienna, has been consulted on hydrographic and hydraulic questions arising in the dominions of the Argentine Republic. There he found himself launched on one of the largest rivers of the world. Second only to that *regina fluviorum*, the Amazon, the Paraná and its affluents form the main outfall of a vast triangular area, bounded by the Andes on the west, by the southern watershed of the basin of the Amazon on the north, and by the mountain chains and ridges that flank the Atlantic coast of South America on the east. From the delta of the Amazon to that of the Plata, a range of thirty-five degrees of latitude, the rivers that enter the Atlantic derive their waters from a succession of broken and interrupted versants (the total area of which is but small when compared to the great central district, with its numerous ramifications) the unevaporated rainfall of which tends to the estuary of the Plata. The basin of the Amazon, with its *embouchure* lying on the equator itself attracts a heavier rainfall than that which visits any other portion of the surface of our planet. But its area is inferior to that of the watersheds converging on the Plata. It is to the greater depth of the equatorial rainfall, that the superiority of the volume of the Amazon, as compared with that of its southern sister, must be principally attributed.

The estuary of the Rio de La Plata, if we consider it to fall into the Atlantic at Monte Video, is nearly seventy geographical miles in width. Trending from the northwest, in a distance of 150 miles, it narrows irregularly, to a width of about thirty miles. At this point, the broad, deep channel of the Uruguay, lying on the meridian, makes a far more imposing show, as far as the map is concerned, than do the two less variable streams, or rather river mouths, by which, under the names of the Paraná Guayazu and the Paraná de las Palmas, the mighty central flood, stealing through its own delta for a distance of sixty miles from the division of the streams, enters the common frith.

The Uruguay, however, is rather a colossal torrent than a gigantic river. Its volume presents extraordinary fluctuations. It is at its lowest in December. About 200 miles above its mouth, or last contraction of width, at Higueritas, the Uruguay flows through a rocky channel, called the Corralito. The length of this natural canal is stated at about 700 feet; its width at 145; and a current of six feet deep, flowing at the rate of five miles an hour, represents the volume and flow of the river. This is rather more than two-and-a-half times the estimated summer flow of the Thames. But in the great periodical rise of the river, this fair-weather channel is completely submerged and lost to view. The great flood, which occurs in September and October, rises at the rate of three feet per diem, till it attains a height of from forty-five to fifty feet above the low-water line at Salto, a port two miles above the Corralito. The cross-section of the river, during flood, is more than five times that above estimated. But this proportion gives no idea of the increase of volume, which is due not only to the enlargement of the water-way, but to a more than tenfold increase in the velocity of the current.

The steady and constant flow of the Paraná forms a remarkable contrast to the violent fluctuations in the supply of the Uruguay. An immense body of water is constantly thrown into the Atlantic by the former noble stream, and its low-water supply never sinks, we are told, below the half of its flood. The geology, and even the actual area, of the watershed districts drained by these two great affluents are but imperfectly known. But we may almost venture to assert, from the evidence of these contrasted phenomena, that the Uruguay must be fed from a larger proportionate area of impermeable strata; while the main part of the water of Paraná is shown, by its steady flow, to have been subjected to the retarding and distributing action of subterranean storage and filtration. This at least, is our European, and we may say, our English experience.

The Paraná is the largest river on the surface of our planet of which we have any exact knowledge. For that knowledge we are indebted in no ordinary degree, to the patience and skill of M. Révy. At a distance of 200 miles from the island of Martin Garcia, which is situate on the La Plata estuary, at nineteen miles below the entrance into the water of the Paraná Guazu stands the town of Rosario a place of some commercial importance, and the largest town on the banks of the river. "It is built," says M. Révy, "on the margin of the bluff, about eighty feet above the river, and the town reaches from the main land down to the Paraná. Some desultory attempts at

engineering stare at us in the shade of a number of strange structures, supposed to be piers; which a number of vessels anchored along the margin of the river seem rather to avoid than to court. Vessels drawing fifteen feet of water may come up as far as Rosario at all times, during the lowest level of the river. The rise of the Paraná from ordinarily low water to ordinary flood level is here about twelve feet, and the flood level is always maintained for three months."

Thirteen miles below Rosario occurs a straight reach of the Paraná about five miles in length. The width is 4,787 feet from margin to margin at low water. The depth increases, by a gentle and regular slope, from that of a few inches, on the left shore, to seventy-two feet, at a distance of about 1,100 feet from the right bank. Thence it rapidly shallows to about twelve feet, and then rises gradually to the foot of a vertical cliff forming the right-hand shore of the river.

At this point, three hundred and twenty miles above the junction of the Plata with the Atlantic, a series of measurements have been taken by M. Révy; to whom the students of hydraulics will hereafter owe no small debt of gratitude. The largest accurate measurement of any river section yet attempted, has there been carried out; under arrangements that reflect much credit on the engineers who have planned and accomplished the work. We wish to give our readers some idea of the grandeur of the river, before calling attention to the contribution made, in the present volume, to geographical, or rather hydrographical science. We shall therefore return, a little later, to the description of the method adopted for gauging the volume of the stream; only remarking that the cross-section, in this locality, of the ordinary flood of the river, gives an area of 243,000 square feet. This large superficies, however, is far from representing the entire water-way of the Paraná; as the left bank is, on occasions when the flood level is attained, submerged for many miles; and although the current over the hidden bank and islands is small, yet a considerable volume of water passes over the great additional sectional area. But even the ascertained section is hard upon the double of that occupied by the October flood of the Uruguay, before cited. In January, when the observations were made, the low-water sectional area of the Paraná was found to be 184,858 superficial feet; or, in round numbers, three-fourths of the area in flood time. The average depth of the section taken in January was forty-seven feet six inches; the extreme depth, seventy-two feet. At times of exceptional rises of the water, such as occurred in 1858 and 1868, this great depth has been increased by twenty-four feet. But that increase, although amounting to thirty-nine per cent. of the smaller dimension, represents not only a factor, but also a function of the second order of the increased volume of the flow. It is from the observations to which we now refer, that M. Révy has been enabled to indicate a new aspect of the great hydraulic law of the proportion of current to depth. We shall presently find that this ratio, is, at all events approximately, represented in this instance, by the ratio of the squares of the depths. That is to say, in round numbers, that the velocity of the Paraná in flood, is to its low-water velocity as 1 to 7.

If we endeavor to estimate the volume of water thus poured into the Atlantic, by any definite measures of capacity, we shall run the risk of attempting to grasp ideas, and finding that we have only succeeded in accumulating figures. The lowest unit that seems to be applicable to such enormous volumes is that of a million of tons. But who can present to his mind any accurate idea of a million of tons of water? We shall find a more illustrative, though still a very rough, mode of comparison by taking, as in the case of the Uruguay, the discharge of the Thames for a unit of comparison. We labor under the disadvantage that the most important discovery made by M. Révy, in the pursuit of his very elaborate survey, that of the law of the relation of depths and currents, was arrived at late in the course of his observations. The observations are sufficient to show the inaccuracy of the ordinary mode of calculation, and thus to prevent us from attempting to gauge the flow of a river by taking any percentage of the surface velocity as the mean velocity of the stream. Unfortunately, however, they are not accompanied by those measurements of the bottom current which this very experience shows to be so needful. It is therefore only approximately that we can estimate, from the details before us, the low-water flow of the Parana at 600 times that of the Uruguay; a movement

of water which is from 2.5 to 3 times that of the Thames, according to the highest estimate of its flow. In other words, the total body of water which the Thames pours into the Channel, in the course of a twelvemonth, is only equal to that which passes the Rosario section of the Parana, in less than twenty-four hours. Again we seem to arrive at the limits of the receptive power of the imagination, in dealing with such enormous volumes.

A comparison of no trifling interest may hereafter be drawn between the natural scale which has been formed, for the decipherment of future geologists, by the Parana, and the corresponding record inscribed by the Nile. From the first cataract (which may be compared in some respects to the Decimante mouth of the Parana), to the northern limit of the delta of the Nile, is a distance very closely according with that from Decimante to Monte Video. In each giant river a double system exists, that of valley course, raised by deposits from the water, and that of estuary. But in the Nile, owing partly to the comparatively narrow bed afforded to its flood, and partly to the different physical conditions of the two rivers, the seaward part of its course is that in which the largest deposits occur. In the Paraná the reverse is the case. The delta of the Nile may be roughly measured as a triangle of some 100 miles in altitude, and as many in base. The unfilled part of the sea channel of the Paraná, which is the Plata estuary, is 150 miles in length, by from 70 to 50 miles in width. It is not only in the division of the longitudinal course of the river into valley and estuary, or land formed, and land in the course of formation, by the deposits of the current, that the Paraná resembles her mysterious African sister. The union of steady, perennial, flow from a distant head-water, with periodic flood, thrown in from a distinct affluent, which is displayed by the confluent streams of the Nile and the Atbara, may be noticed in the confluence of the Paraná and the Uruguay. The length of the Parana, indeed, is only estimated at some two-thirds that of the Nile; but the volume of its flow appears to be far greater. A considerable allowance has to be made for the greater loss, by evaporation, to which the Nile is exposed in the course of a thousand and more miles of tropical flow. But the enormous volume attained by the Paraná, in its highest or extraordinary floods, exceeds anything which the hydrometer has yet attempted, with any approach to accuracy, to estimate. M. Révy has remarked, as before cited, that the summer flow of the Paraná never falls below half of its winter or linary flow; the latter, we learn from the sections, rises twelve feet above summer level. But the great floods rise to twenty-four feet, and the additional velocity at which, in accordance with the observations of M. Révy, to which we shall presently refer, this increased volume flows, is such as to give a result of truly colossal magnitude. From M. Révy's data we can estimate the summer flow of the Paraná, at Rosario, at forty milions of metric tons per hour; the ordinary flow at eighty-three millions of tons per hour; and the great floods at 169 millions of tons per hour; or four times the summer flow, independent of the escape over the marshes.

We have been led to linger on the descriptive portions of M. Révy's book, partly by the fascination which is exercised on the mind by the extraordinary magnitude and grandeur of the scenery and natural phenomena observed; and partly on account of the weight that is given by that magnitude to those scientific deductions which give to the work a high professional value. We will endeavor to give the gist of the discoveries of M. Révy, in language that shall be intelligible to the general reader. The engineer we refer to the work itself, as a model of exact field notation, illustrated by clear and elegant diagrams. Nor can we fail to note the unusual excellence of the workmanship by which the lithographer, Mr. Thomas Kell, has so nearly approached the beauty of copper-plate engraving.

Rivers, it is trite enough to remark, are generally regarded as running, more or less, down hill. That their velocity depends on the fall, or gradient, of the valleys, to the bottom of which they betake themselves, is a no less self-evident proposition. But we can well understand that the general slope of a valley may be seriously interfered with by local obstacles. In our own Cumberland and Westmoreland lakes, as well as in many other parts of the world, the traveller may observe, from some commanding situation, how rocks rise, or hills seem to have been thrown down, across the mouth

of a valley; with the result of damming up the waters of the stream, into those placid expanses that lend so peculiar a charm to the landscape.

The occurrence of lakes, in the actual course of a river, may explain the reason why we are in the habit of measuring the velocity of streams by the inclination of their surface rather than by that of their channel. As water obeys the great law of gravitation, with a more unhesitating precision than any other material on which we are able to experiment in mass, we have no difficulty in calculating the theoretic velocity of the surface of a river, from its actual inclination, or fall per mile or per foot. So, on the other hand, we may arrive at the rate of that inclination, from accurate measurement of the velocity of the current.

Thus far all is plain and simple. But the question arises, what is the total flow of the stream, or what is the relation between the velocity of the centre of gravity (that is to say of the mean flow of the actual volume) and the velocity of the surface-current?

In attempting the solution of this question, we have to inquire what it is that tends to retard the flowing of a river. We know that falling bodies increase their velocity, in a known proportion, according to the time occupied in their fall. We are aware that this law of freely-falling bodies, applies to bodies that run or glide down a slope or inclined plane. Thus if a railway carriage be set in motion on the top of a long steep gradient, such as that of the Lickey incline near Bromsgrove, it gently creeps downward for the first few yards, mends its pace as it advances, and acquires a dangerous and irresistible speed as it reaches the foot of the plane. The cause that prevents a similarly marked increase in the velocity of a stream, when the inclination is continued, is the friction of the water against the sides and bottom (chiefly against the bottom) of the channel. In a rapid and rippling brook, when a child rakes up the sand from the bottom, or a fisherman throws a handful of ground-bait into the water, it becomes at once apparent that the upper portion of the stream *overruns* the lower currents. The bottom drags back the flow, and the river is perpetually running *over itself* from top to bottom. Thus, of two particles of water, one at the surface and one at the bottom of the stream, the former is constantly gaining on the latter, and, in the course of a mile or so, will have left it far behind in its seaward course.

It is this relation between the top and bottom flow on which depends the actual discharge of a river. The subject is one that has by no means been neglected. Distinguished men have made experiments in order to gauge the flow of rivers; and the results of their observations have been embodied in certain mathematical formulas, which, if not absolutely identical, do not very materially differ from one another in their results, when applied to our modest English rivers. They are chiefly based on the experimental data of Du Buat, with additions by subsequent investigators. The formula of Weisbach is that quoted by Professor Rankine in his latest and posthumous work, the "Mechanical Textbook." The object of that formula is to ascertain the proportionate friction of a stream on its bed, represented by what is called the coefficient of friction. This formula refers to velocity alone, and only relates to depth in a roundabout way; that is to say, as it is indicated by velocity. The direct importance of this relation appears to demand more distinct recognition. It is not surprising that M. Révy found hydraulic formulas, based on observations of smaller rivers, to be inadequate, when he sought to apply them to the mighty flood of the Paraná; or that the great Mississippi survey should have been deprived of its anticipated value by the imperfection of the mode of measurement adopted by the surveyors.

It soon became clear that any attempt to ascertain the volume and flood of a river like the Paraná, by empirical formulas, was nothing more or less than guesswork. Actual measurement of widths, depths, and velocities was indispensable. The method adopted by M. Révy for ascertaining the cross-section of the Paraná, by a combination of soundings and sextant observations, may be studied with advantage in any hydrographic survey. If it cannot be called altogether novel, it is highly commendable, as an example of exactitude, alike in rule, in habit, and in expression. For the measurement of the velocity of the stream, as to which the ordinary clumsy expedient of floats cou'd give no reliable data, an instrument called the current-meter was employed. This resembles a little mill —windmill, we were about to say, but at

all events a vane—of a foot in diameter, which is turned with rapidity when immersed in a running stream. The axle of the vane gives motion to a small train of wheels, which move a couple of indexes; as in a gas-meter, or as in a watch. These indexes denote the number of revolutions made by the vane; which is kept at right angles to the stream by a sort of rudder attached to the meter.

M. Révy does not claim the invention of the portable means of observation: but he has introduced two important improvements in the method of using it. One is, that instead of trusting to the ingenuity of the maker, to convert revolutions into feet and furlongs, the actual reading of each meter should be ascertained, by moving it through perfectly still water for a measured distance. This furnishes an equation for the instrument, allowing for the loss by friction, which is constant, and not proportionate to the velocity; so that the exact number of revolutions is booked on the spot, and the reduction into length is made afterwards. The other improvement consists in the attachment of the meter to an iron bar, six feet long, which M. Révy calls the current integrator, which can be raised or lowered at will from a boat, so as to ascertain the velocity of the current at any required depth.

The bulk of the observations made upon the currents of the Plata, the Paraná Guazu, the Paraná de las Palmas, and the Uruguay, were surface velocities alone. It was supposed that, from these observations, the mean velocity might be ascertained by formula, as before mentioned. In dealing with phenomena of such magnitude, however, an important fact became apparent. The velocity of the river, at any given cross-section, proved to be directly proportionate to the depth. Thus if a shoal occurs in the middle of the channel, the velocity of the current over the shoal is less than that of the deeper water on either side; and this diminution of speed is proportionate to the loss of depth. So direct is this relation, that a plan of the surface velocities, if projected on the appropriate scale, coincides very closely with the section of the bottom of the river. Any want of parellelism between the two curves is capable of explanation, either by the curvature of the banks, or by some physical irregularity of the channel.

This important law, now for the first time brought distinctly forward, renders the actual measurement of under-currents an evident necessity. But the grand result of the subaqueous measurements was not perceived in time to allow of the more extended experiments which are still requisite for the full elucidation of the subject.

So far as the actual experiments go, the result was, first, that the greatest rapidity of the current is at the surface, secondly, that the increase of this rapidity is in the simple ratio of the distance from the bottom. Thus, both by calculation and by measurement, the mean velocity of a stream at any part of its width, occurs at half the depth of the water, at that part, from the surface.

This result is so consistent with the former law, that the surface velocity is proportionate to the depth, that it might even have been arrived at by analysis. But it is incomparably more satisfactory, in the present state of our knowledge, to have the testimony of direct experiment.

No small increase of professional knowledge is thus gained. But now occurred an experiment which seemed, on the first blush, to run counter to the theory. In two successive measurements of the current of the Plata, the apparent anomaly was detected, that a decrease of the velocity of the surface current was accompanied by an increase of the velocity of the bottom current. Such an unexpected contradiction of an accepted theory would have been set down by nine men out of ten to error of observat on. The field-book would, very likely, have been "corrected"; that is to say, *cooked*, and the fatal expression, "we know that cannot be right," might have strangled a discovery, the importance of which to the study of hydraulics it is not easy to over-estimate.

M. Révy, however, is evidently a man who has great veneration for truth. He relies, and justly relies, on the accuracy of his observations, and on the acuracy of his record of these particulars. He has that prime qualification of the great discoverer—philosophic patience. He prefers to confess ignorance, and to wait for knowledge rather than to invalidate actual observation, by forcing it to fit the theory. And he had his reward. It was owing, not to any special experiments, but to the general systematic excellence of his arrangements that he obtained the clue to this mystery. He found that the water of the Plata was act-

ually sixteen inches deeper, on the occasion when the under-current was more powerful. Here was a third, and most unexpected case, of the great law of the dependence of velocity on depth. The river was actually flowing in greater volume at a time when, to a superficial observer, it was slackened in its course. We can readily understand that the water was banked up by its own mass, and that the surface-fall at the point measured was, therefore, less than on the preceding occasion. In obedience to known hydraulic law, this decreasing surface-inclination was indicated by decreased velocity of surface-current. But the power of the whole moving mass of water was greater, in proportion to its depth. And thus, while to the superficial gaze the velocity was less, the mean velocity was greater, and the river swept with more resistless energy over its bed. This luminous observation is the opening of an entirely new chapter in hydraulic science. It is, in fact, a case of the law of the relation of speed to depth; but it is one that could scarcely have been arrived at by theory; although now that it is experimentally ascertained, its theoretical reason is ascertainable.

At this point M. Révy has paused. He might well have gone a step farther; but the modesty of his conclusions is perhaps as remarkable as their importance. He has drawn up no formula as the result of his observations. To explain and justify such a formula would, he tells us, require a separate treatise. He has been content to bring his observations before the world. He attacks no one; he corrects no one. He desires no one to control their observations by his. He simply says such and such were the facts, on such a day in such a locality. He places the raw material of science in the hands of his professional brethren; and invites them to make as free a use of it as he does himself. He truly says that the facts recorded in his pages will supply ample material for the contemplation of those who love their profession for its truth and for its beauty.

We are not satisfied without taking a step farther. We must be cautious not to generalize too hastily. We cannot endorse the observations of M. Révy on the subject of mean hydraulic depth. To these mighty rivers the retarding influence of the sides of the channel is almost unfelt. But we cannot doubt that it exists; and that it is improper to neglect that fact, especially with reference to smaller streams. We must hesitate to deduce great laws from a very limited number of observations. But, on the other hand, when we regard each new position, laid down from observation of the movements of these great masses of water, as presenting a distinct case of the same law; and when we find authentic results accurate, within the limit of precision of observation; we think it well, under due reserve, to indicate the upshot of experiment. By comparing accurately the volume of flow of the Plata, on the two occasions above described, making due allowance for the retardation by loss of head, we find the increased mean velocity of the river to be in exact ratio of the squares of the depths on the two days under investigation.

If this very simple rule be ultimately shown to be normal, the results that it will have on our hydraulic engineering will be marked and precious. Thus in the recent proposals to draw a new water supply for London, from the watershed of the Severn, of the Wye, or from the Ulswater system of lakes, we find one engineer propose a canal of 30 feet wide and 10 feet deep for the main stream; and another, one of 15 feet wide and 14.5 feet deep for a not very different quantity of water. The fall in the latter case is estimated at from sixty to twenty-four inches per mile. But with such a variation of level, the cross-section of the channel must be proportionately increased or diminished. And, surface inclination being the same, although the sectional area of the last-named conduit is only about two-thirds that of the former, the actual delivery, according to M. Révy's observations, owing to the increased velocity due to the extra depth, would amount to more than that of the shallower aqueduct. Not a glimpse of such an idea appears in the report of the Royal Commission of 1869 on water supply. Here the observations on the Paraná come home to us with much interest. There is another point untouched by M. Révy, but which his observations are calculated to suggest. He speaks of the bottom-flow of a river being possible at any velocity, from zero up to the surface-flow. We do not see that the upper limit is definite. At the mouth of the Paraná, where the channel is only half a mile wide, and where even the di-

vided body of water represents a mighty volume, not even a ripple is perceptible on the surface. As we read the description, there is no evidence of perceptible surface-current, or of sensible head of water. If this be so, the under-current may be powerful, while the surface-current is *nil*. We must have this important question elucidated, by means of the sounding lead and the current meter; nor can the matter be alowed to rest until this be done.

Again a question arises, of no little importance to the hydrographical department of the Admiralty, as well as to the science of physical geography. We have heard at times, of an under-current in deep water at the Straits of Gibraltar. The escape by an under-current, from the Black Sea, of some portion of the enormous contributions poured into its waters, has been more recently suggested. The ascertainment of the exact facts, in each locality, which the use of the current integrator renders easy, ought not to be postponed. We trust that the Admiralty will show promptitude in obtaining and affording the information, which is thus shown to be within its grasp; such an investigation will throw much light on the subject of Mediterranean evaporation, and on the hydraulics, not only of great rivers, but of the sea itself.

It cannot be considered as a circumstance redounding to the national credit—although it is highly to the credit of distinguished individuals—that we are dependent on *amateur* exertions for the knowledge that we possess of the rainfall of England and of the kindred questions that affect the origin of our rivers. More than 1,500 private observers now contribute daily observations, on which Mr. G. J. Symons bases his Annual Tables of British Rainfall. The value of these observations may be estimated from a knowledge of the wide difference that exists between the annual rainfall at stations not very widely distant from one another. Thus at Stye Head Pass, in the Westmoreland district, 243.98 inches of rain fell in the course of 1872; or upwards of 20 feet of water; a depth greater than that which we now estimate that the evaporative power of the tropical sun draws up from the surface of the ocean. During the same year, the rainfall measured at Silsoe was only 26.18 inches. When we find that the spirited and unremunerated efforts of men, who follow science only for the love of truth, are thus active, it would be ungracious to grumble at the want of conclusive observations as to evaporation, as far as they are concerned. But we find that Mr. Miller, who has made uninterrupted observations on the evaporation from water, for eleven years past, is still unable to give constants of evaporation.

An unusually favorable opportunity presents itself for the actual determination of the most steady and remarkable case of evaporation that occurs on the surface of our planet. In its headlong course from the foot of Hermon, the Jordan (well-named the descender) may almost be said to consist of three continuous cataracts, divided by two lakes, and terminating in a third. From the surface of that bituminous sea, the water of which contains nearly one-fourth of its own weight of salts, the whole supply brought down by the Jordan and its affluents is exhaled in invisible vapor. With the increased supply, when the swollen river overflows its banks, the waters of the Dead Sea rise, and its surface extends, until its area is such that the evaporation again balances the flow. The steady pulsations of this great natural hygrometer deserves the most attentive study. The Ordnance Survey of Palestine, the rapid progress of which promises to enrich our atlases with a map of unusual precision and beauty, may be expected to supply exact information as to the area of the Dead Sea at different seasons of the year. If with this is connected an accurate measurement of the volume discharged by the Jordan, we shall be furnished with evaporative data of the highest value. We admit that the geological features of the spot are of unrivalled interest. We trust that careful surveys may throw much light on the original course of the drainage, from the North of Syria into the ancient embouchure of the river at Akaba. It is far from unlikely that a connection between geological action, and historic dates, as marked as that which has rendered famous the Temple of Serapis at Pozzuoli, may here be detected. But whatever may be the results of exploration, in a geological or an archæological direction, we cannot but express the hope that the valuable data, which this district offers to meteorological science, may be now exhaustively collected. If we are taught hydraulic laws by the Paraná, we may increase our knowledge of the laws of evaporation from the survey of the Dead Sea.

THE DRY EARTH SYSTEM.

From "Iron."

The disinfecting powers of common earth have been known from time immemorial. The ancient Israelites, probably without knowing the cause, were as familiar with the results as we ourselves are. And those curiously unprogressive people, the Chinese, have always been acquainted with the fact that the mixing of earth with excreta render the latter innocuous. The lessons thus taught in the past have, however, been neglected with us until the last few years, when an apparently accidental disposal of the excreta of a private house led an English clergyman to make a number of experiments, which led to the invention of the dry earth system—one of the most, if not the most, successful of the many devices yet resorted to for dealing with this important subject.

In the year 1858 the Rev. H. Moule, vicar of Fordington, in Dorsetshire, was troubled with the nuisance caused by the cess-pool of his house. Like almost all cess-pools and middens in this country, it was close to the well, and thus threatened the complete pollution of the water which the family had to use for all domestic purposes. To obviate this danger, and to get rid of the nuisance, Mr. Moule abolished privies and water-closets, and placed small buckets beneath the seats for the reception of the excreta, the contents of which were regularly emptied into a trench made in his ground for that purpose. In a short time he discovered that the effect of the earth on the excrementitious matter was to totally deodorize and disinfect it. This discovery led him on a step further in his experiments, and he now mixed dry sifted earth with the contents of the buckets, which were then emptied and left in a shed to consolidate. In an account of his proceedings, furnished by Mr. Moule, it is stated that "About three cart-loads of earth were used in this manner during a period of five or six weeks, for a family of seventeen persons, and at the end of that time he found that the first portions of earth were sufficiently dry to be used again. It was while using the same earth for the fifth time that he published the results of his experiments, and inaugurated his system—saying that it was founded on the rapid and effectual disinfecting powers of dry earth; in the capability of using the earth again and again, until it became soil as a manure; and on the fact that the system dealt with the sewage and cess-pool difficulty at its very source. He then devised the mechanical means of using earth in an ordinary closet or commode, and in 1860 he obtained a patent for it. He ascertained that a pint-and-a-half of dry earth was sufficient for each visit to the closet."

This system has now been tried in many places in England and in India, and always with success. In our great Indian Empire it has secured for itself a permanent position, and its use is authorized by the Government, and a grant of £500 was made to Mr. Moule by the Governor-General in Council, and sanctioned by the Secretary of State for India.

Messrs. H. J. and J. W. Girdlestone, civil engineers, state that by a long series of experiments, the following facts have been tested and re-tested, and at length completely established as principles:—1. That any surface earth, and almost any clay, will deodorize excrementitious matter; but that mud and chalk will not. 2. That such earth, if dried and sifted, has such power of absorption that it is capable of receiving both liquid and solid excreta, and of rendering their removal practicable without offence, and also without any loss to the value of the manure. 3. That a very small quantity of earth is required, and that the same portion of earth may be repeatedly used with the same effect. 4. That the action of the earth on the excreta is immediate, all fermentation being prevented, the obnoxious agent being dealt with at once, and in detail. 5. That, while the earth absorbs the excreta, they in their turn possess a decomposing power such that any extraneous matter deposited with them disappears in a short time. 6. That the absorption and deodorization of the excreta result in preventing infection.

This system is now at work at a large number of public institutions, as well as having been applied to a still larger number of private houses in this country. Among the places now using it we may mention the Lancaster Grammar School, the Dorset County School at Dorchester, St. Mary's College, Oscott, near Birmingham, the Broadmoor Criminal Lunatic Asylum, the Sanatorium at Weston-Super-Mare; at several villages on the estate of Baron Rothschild, near Wendover, in Buck-

inghamshire, and at, notably, the volunteer camp at Wimbledon. The last-named place may be safely selected as an illustrative example of the efficiency of the system for the experiment there was, in fact, a crucial one. In the *Lancet* of August 1, 1868, the result is described in the following words:—"The strongest possible testimony has been borne to the efficiency of the 'dry earth system,' which was in use throughout the volunteer encampment at Wimbledon. Last year the system was experimentally tried, and resulted so satisfactorily, that it was determined to adopt it this year exclusively. There can be no question that the test to which the system has been subjected was a crucial one, considering especially the excessive heat, which, although favorable to the rapid drying of the soil, was yet creative of other conditions increasing the difficulties attendant on fæcal deodorisation. Altogether some 148 dry earth closets and urinals were in operation at Wimbledon, and when it is remembered that about forty or fifty of these closets were used daily by not less than 2,000 men, without the slightest annoyance to sight or smell, the measure of success is complete. It is not too much to say that no other system is possible at Wimbledon, where circumstances have all to be made to square with temporary requirements. But if the dry earth closets can stand the test of such repeated use as they have lately had, it seems to us to follow as a matter of course, that they must be in every way suitable for the exigencies of rural districts."

Dr. Buchanan ascertained, from careful inquiry at the Camp, "that during the meeting of the volunteers, which lasts for fourteen days, as many as 3,000 persons use the closets daily, and 10,000 the urinals. In the course of that time 140 tons of dry earth are expended in the closets and urinals, the closets requiring 4500lb. per day, and the urinals 17,900lb. This is in the proportion of 1.5lb. of earth for each operation at the closets, and 1.79lb. for each visit to the urinals. When the earth was dry and of good quality it was found that the product was solid and inoffensive; but when, as in the preceding year (1867), it was of a peaty nature, the compost was wet and warm. Taking these facts into consideration, Dr. Buchanan concludes that 4½lb. of dry earth would be a proper supply for each person daily, 1½ lb. being allowed for each visit to the closet or urinal, and three such visits daily. A village of 1000 inhabitants would, therefore, require 5001b., to just two tons of dry earth per diem.

In the month of January of the present year (1874), we paid a visit to the Sanatorium at Weston-super-Mare, at which the dry earth system is in use. We examined the process, and from all the information which we could obtain on the spot—and this was given in the fullest and freest manner—we could arrive at only one conclusion. The system had proved in the highest degree satisfactory and successful.

As regards the value of the product, we learn, on the authority of Dr. Letheby's "Notes and Analyses," that it seems, "like all such materials," to be variously estimated, according to the quality and the demand. In the City of Lancaster, where the material is mixed with the refuse of the shambles, and with urine from some of the public urinals, it realizes only from 7s. 6d. to 10s. per cubic yard, and it just pays its expenses. At the Dorset County jail it sells for £1 a ton, or 10s. per head per annum; but at the county school in the same town, it fetches from £2 to £3 a ton, or 15s. a head. In the experiments of the Rev. H. Moule with material that had been used in closets five times over, it was found that, when contrasted with super-phosphate at £7 12s. a ton, its immediate results were equally good, and its permanent effect on the land much better. In both cases the manures were employed in the same quantities—namely, in the proportion of 1 cwt. to an acre of land. We are not acquainted with many chemical analyses of the product, although two have been published by Dr. Hawksley, which were made by Mr. Evans, of Leadenhall Street, both of them being of material that had been used only once in the closet, and the results are as follow:—

Organic matter, &c.	5·16	22·65
Soluble phosphate of lime	0·53	1·10
Potash	1·06	1·10
Alkaline salts	—	4·10
Aluminia, sand, &c.	—	71·5
	100·00	100.00
Nitrogen equal to ammonia	0·33	0·79

These samples were valued by Mr. Evans at £1 and £1 10s. per ton respectively: but it is evident that if the material had been used four or five times over, it would have

been considerably more valuable than this."

In his report to the Privy Council, Dr. Buchanan gives the following summary of the advantages of this system: —

"(1.) The earth closet, intelligently managed, furnishes a means of disposing of excrement without nuisance and apparently without detriment to health.

"(2.) In communities the earth closet system requires to be managed by the authorities of the place, and will pay, at least, the expenses of its management.

"(3.) In the poorer class of houses, where supervision of any closet arrangements is indispensable the adoption of the earth system offers special advantages.

"(4.) The earth system of excrement removal does not supersede the necessity for an independent means of removing slops, rainwater, and soil-water.

"(5.) The limits of application of the earth system in the future cannot be stated. In existing towns, favorably arranged for access to the closets, the system might at once be applied to populations of 10,000 persons.

"(6.) As compared with the water-closet the earth-closet has these advantages: — It is cheaper in original cost, it requires less repair, it is not injured by frost, it is not damaged by improper substances being thrown down it, and it very greatly reduces the quantity of water required by each household.

"(7.) As regards the application of excrement to the land, the advantages of the earth system are these: The whole agricultural value of the excrement is retained; the resulting manure is in a state in which it can be kept, carried about, and applied to crops with facility; there is no need for restricting its use to any particular area, nor for using it at times when agriculturally it is worthless; and it can be applied with advantage to a very great variety, if not to all, crops and soils. After the disposal of excrement by earth, irrigation will continue to have its value as a means of extracting from the refuse water of a place whatever agricultural value it may possess, for the benefit of such crops and such places as can advatageously be subjected to the process.

"(8.) These conclusions have no reference to the disposal of trade or manufacturing refuse, which it is assumed ought to be dealt with as belonging to the business in which it is produced, by the people who produce it, and not to come within the province of local authorities to provide for.

VENTILATION;

WITH SPECIAL REFERENCE TO THE TURRET-SHIP "DEVASTATION."

By M. Blank, Esq., R. N.

From the proceedings of the Junior Naval Professional Association.

The subject of Ventilation, especially in connection with the latest novelty in armor-plated turret ships, cannot but prove an interesting one for consideration by the members of this association. We are all vitally concerned, and have probably at some time or other, suffered from living in a vitiated atmosphere, the result of imperfect ventilation, or no ventilation at all. That the question is an important one, is now fully admitted, and it is a fact to congratulate ourselves upon, and the service generally, that it is beginning to receive the amount of attention it deserves.

In venturing to address you, my hope is, that the paper I shall have the honor to read, may serve chiefly as an introduction to addresses from gentlemen better qualified and more conversant with the subject. I can claim originality for no part of it, neither have I been able to cull largely from standard authorities, the absence of a public library being a drawback in preparing papers on anything approaching scientific subjects.

What do we understand by ventilation? a subject that has received its share of attention from learned Professors and scientific societies, few of them holding identical views, as to the mechanical, or other means to be employed. Let us divest it of all technical and theoretical complication and be content to know and speak of it as the necessary and simple operation of substituting one volume of air for another, by one of two processes, abstraction of impure air and the consequent substitution by grav-

itation of pure, or the forcing in by mechanical means of pure air, and the expulsion of impure.

It would far exceed the limits of the present opportunity, to recount the thousand and one modes employed to secure a change of air in our dwellings, public buildings, ships, &c., &c., we should but confuse ourselves in the multiplicity of ingenious, but often mistaken devices. One thing is certain, that in attempting any system of ventilation, the more nearly we copy the simple and beautiful operations of nature the more surely will success crown our efforts.

There was a time when the origin or causes of natural phenomena were mostly shrouded in mystery, and the effects ascribed to the influence of particular and presiding Deities; but in our day, thanks to the almost superhuman achievements of our students and philosophers in the varied and extensive domains of scientific research, we know that the elements yield implicit obedience to immutable natural laws, and that the rushing wind, and the gentle breeze, are alike due to a compliance with the fixed laws of gravity;—the rarefaction of air on one portion of the earth's surface, and the settling of colder and heavier strata to supply its place; and it is this simple natural law we must bear in mind, and upon which the entire principle of ventilation depends.

As an illustration, I would refer you to the old and time-honored system used to ventilate the shafts and workings of coal mines. The shafts and passages are merely divided by a partition called a bratticing, one side is used for the exit of rarefied foul air, and the other free for the descent of fresh. A fire is kept burning on the upcast side of the partition—generally at the bottom of the shaft—which rarefies the air, increases its bulk, and therefore decreasing its specific gravity; the balance is destroyed in the two sides of the shaft, the lighter and foul air giving place to the heavier and pure; and this will continue though the air may have to travel miles before it commences the return journey.

It is a great mistake to suppose that a space say the hold or lower deck of a vessel, can be ventilated by merely cutting large apertures or hatchways; nothing of the kind can be done, a diaphragm must be inserted. A fire placed on the deck would burn badly without the upward and downward currents which must be separated; the partition should go nearly to the bottom of the space and be carried high as possible above the aperture, then there will be ventilation.

Most of you have no doubt noticed the strong draughts of cold air rushing from the engine-room to the stoke-hole, that is produced by carrying a diaphragm—the bratticing of the coal mine—from the upper deck down as far as practical, the heat of the boilersand funnel rarefies the air inside the partition, it ascends, and colder air finds its way through the engine room from the lower deck; and from the outermost sides of the hatchways divided by the diaphragms, the supply of air for the furnaces is also brought by the same means.

This arrangement has been of incalculable benefit, and the credit of introduction, (not invention,) I believe is due to Mr. Baker, Chief Inspector of Machinery; it was perfected at Chatham by a long and careful series of experiments conducted by Admiral Halsted and Mr. Langley, Chief inspector of Machinery.

I think I may safely affirm, that with the exception of the simple but necessary arrangements for working mines, ventilation as a science is the offspring of the latter half of the nineteenth century. The laws and principles were undoubtedly known and understood, but rarely reduced to practice. In the mansions of the wealthy and the palace of royalty, the removal of impure air and the supply of pure was left to chance, or but noticed as of little moment, while in the cottages of the poor, the crowded dwellings of the masses, and the reeking stifling dens that harbor the refuse and dregs of our city populations, the gaunt demon of destruction stalked unnoticed and unchecked, his greedy maw supplied with a plenitude of miserable victims by those twin fell sisters—disease and crime. Even at the present time in this 16th century, the boasted age of civilization, of princely bequests and unbounded benevolence, millions of our fellow men are left to wither and rot, the victims of culpable ignorance or grasping criminal avarice; and even where efforts are made to remedy such short-comings, the stream of pure air that should be cherished as the breath of life is fought against as an enemy; and this is not confined to the lowest class, for how often do our medical men find their patients dying from want of pure air, with even the chance apertures of their rooms almost hermetically sealed. Unfortunately, ventilation so called is too often but a series of draughts which

are alike prejudicial to comfort and health, and at the present time particularly objectionable, when every combustible atom needed to supply the caloric for our internal economy and external warmth, is so much dearer. No wonder we so often see sickly inmates and smoky chimneys. Where is the air to enter when the chinks of door and floors are pasted over? And a few more coffin nails added in the shape of padding for windows, &c. The air can only enter in fitful gurglings down the chimney as it does in a bottle when fluid is escaping.

And what did our brave old salts of the Pigtail, or even down to much later eras, know or care for ventilation? How many of them succumbed to the dread unknown, and were unaccountably lost to the service—who shall tell! We know and remember with pride but their glorious achievements. True, they had the advantage of many safeguards absent at the present time; they were a more hardy and robust class of men than our present race of seamen; though the spaces between decks were more confined than ours, they lived more on deck, wore rougher and perhaps more suitable clothing, knew nothing of the modern effeminate custom of going aloft in sea-boots, wearing gloves and comforters, innovations we have to thank the Russian war for The efficiency of the ship depended entirely upon their smartness and endurance, and they would no doubt have looked with scorn—especially our Pigtail friends—upon the dirty smoky kettles, inelegant double topsails, and patent reefing and truss arrangements; their arduous duties kept them on deck, and balanced the short-comings in ventilation.

They had their proper wind-sails, but these were chiefly used to dry their eternally wet and saturated decks. A properly constructed wind-sail, properly adjusted and trimmed, is invaluable on board ship; but the amount of attention it requires, its unsightly appearance, and the unfortunate faculty of always being in the way, renders it practically valueless.

I need not take up your time in proving the absence of ventilation in our wooden ships, our individual experiences being sufficient. I shall ever remember with loathing, being obliged to remain for some time on the lower deck of a frigate, during a tropical storm, all the hatch covers, &c., being on; it was something indescribable, something horrible.

At the present day, our commanding officers.—thanks to their greatly improved scientific education—are awakening to the fact that proper ventilation tends to the greater efficiency of the ship, by keeping down the sick-list. which reacts on the black list for a healthy body tends to a better mind, better feelings, and more cheerful execution of duty; and *vice versa*, for a sickly complaining man is a nuisance to himself, and of but little use to the service – in fact, he only infects his messmates with his own miserable dissatisfied spirits.

The authorities are insisting upon the strictest attention being paid to all matters of hygiene, and the medical officers upon whom the important duties chiefly devolve are equally alert and fully competent for the efficient discharge of those duties.

Were this enlightened spirit wanting, were these changes not the natural result of a higher culture and more liberal scientific training of our officers, they would have been made all the same; our modern men-of-war, from their peculiar construction, imperatively demand special ventilating arrangements: without, they would soon become mere floating prisons and hospitals, and alike dreaded and shunned by our seamen. and we all know what would be the consequence of a loss of confidence in their ship, either by officer or blue jacket.

In order to fully appreciate the necessity for ventilation and the difficult task imposed upon the designers and constructors of our dwellings on shore and afloat, let us glance at the approximate amount of air required for respiration by one adult person.

Blood, in a healthy condition, is charged with a certain amount of oxygen, during the circuit through the system, the oxygen is taken up and consumed; carbonic acid is formed. the blood becomes venous and unfit for further circulation, till on passing through the right side of the heart and the pulmonary arteries into the pulmonary capillary vessels, it comes into contact with the air drawn into the lungs, where the necessary amount of oxygen—about 4·5 per cent. of the inspiration—is taken up by the blood, and it passes on to the right ventricle, while the expiration takes with it in chemical combination the carbonic acid—amounting to about 3·3 per cent.—acquired by the blood in the grand operation of keeping the fuel in the human furnace in full and effective combustion, which would otherwise as effectually extinguish the vital spark

of human life, as the closing up of a furnace would an ordinary fire; as in the ever-memorable and fatal Blackhole at Calcutta, and in the too frequent suffocations by charcoal, each case the result of excess of carbonic acid.

Every person requires about one cubic foot of oxygen per hour, thus rendering five cubic feet of air unfit for respiration.

If ten men were confined in a room closed at all points, fifteen feet square and ten feet high, equal to 2,250 cubic feet, they would consume the whole of the oxygen in forty-four hours—that is, if they lived so long—but death would take place long before that time. Pure air contains only from 4 to 5 volumes of carbonic acid in 10,000 volumes.

I am unable to state at what point of saturation actual danger to animal life commences, but believe it varies in different individuals, depending upon strength of lung and constitution. We do know that no one can live where a candle will not burn, and flame is extinguished when there is 20 per cent. of carbonic acid in the air; but insensibility sets in long before that degree is arrived at, and there is no doubt it is highly dangerous to breathe air that has already passed through a system perhaps tainted with disease; for not only would the amount of each respiration be deficient in oxygen, but it would be charged with deadly carbonic acid, the pregnant cause of blood poisoning, in its various forms. Air containing 33 volumes in the 1,000, or 3.3 per cent. of carbonic acid has been taken from the lower deck of a vessel at night. Dr. PARKER says, "air containing from 50 to 100 volumes per 1,000 of carbonic acid is fatal to human life, but that a much lower per centage—say from 15 to 20 volumes per 1,000 would produce very serious consequences," the premonitory symtoms being headache, drowsiness, and quickened but less efficient action of the lungs.

From 3 to 4 per cent of carbonic acid is found in the air expired from the lungs; but as the atmosphere of the room becomes unduly charged with carbonic acid, the amount in each successive expiration perceptibly diminishes, thus leaving behind to poison the blood, the difference between the amounts due to perfect and impaired respiration, until the maximum point of saturation is reached, viz., 10 per cent, when common air refuses to absorb any more carbonic acid, the act of respiration becomes useless, and death ensues.

Five cubic feet of air per hour will supply one person with sufficient oxygen; it is calculated that for perfectly healthy respiration, with a mean of 16 respirations per minute, and a mean of 32.5 cubic inches per inspiration, a healthy person would consume 433 cubic feet of air in the 24 hours. A candle consumes the oxygen of 2½ cubic feet of air, and every pound of coal the oxygen of 150 cubic feet of air, so that for every person in a room, there should be a supply per hour of 18 cubit feet of fresh air, for every pound of coal 150 feet, and for every candle or its equivalent 2½ feet; from 50 to 100 per cent. should be allowed in addition for waste. The fact that a candle will not burn in an atmosphere dangerous to life is well-known, and often used as a test before workmen are sent into wells, or other confined places. On board ship the practice is necessary. No man should be sent into a boiler, bunker, or double bottom, that has not been examined for some time, without taking such a necessary precaution. A naked light is sometimes dangerous, for the gas may be of an explosive nature. Safety lamps are therefore now added to the complement of stores.

In attempting to prove the necessity for abundant ventilation, I have taken no cognizance of the effect due to exudations from the skin; this, though of very great importance in any consideration of the question, I am unable to deal with, not possessing the necessary data.

The novel construction of the *Devastation* has necessitated the introduction of a most elaborate system of artificial ventilation, as with the exception of wing passages on the breastwork deck, scarcely any room or compartment could depend upon natural means for supply of air; but though the arrangements are so elaborate and extensive, so far as the supply of fresh air is concerned, the whole is simplicity itself. Fresh air direct from the flying deck is forced by five fans into main trunks, and each and every compartment, cabin, store, magazine, mess-room and office is connected with them, and can regulate its supply of air at will, exactly as in towns, the water and gas companies lay down mains and branches from them to individual houses, to be drawn from at the will of the occupiers; so that in the ward-room, where there are four 3-inch pipes, one in each corner, and fitted with stop-cocks, if the room becomes too warm, instead of ordering the skylights or doors to be

opened, the order will be, "turn on a little more air please," or the facetious member of the mess will request the introduction of a little more oxygen, ozone, &c., &c.

To attempt a thorough and precise description of the whole system of mains and branches in their various ramifications, would require much more time—and I am afraid patience—than we have at our disposal, as well as a series of sketches and drawings with which I am not provided.

The fans are five in number, and are on and under the deck next above the engine compartment. Two are placed on the forward side of the water-tight bulkhead dividing the engine-room from the after stoke-hole, one is on the after side of the bulkhead dividing the forward and after stoke-holes, and two on the forward side of the same bulkhead.

The engines for driving them are placed on platforms, two in the after part of the engine-room, the rest in the upper part of the stoke-hole, below the fans; the motion is communicated by means of bands passing up from the engines to the drums on the fans. The steam for the engines is supplied by the auxiliary boiler, or from the main sets if in use. The fans are "Lloyd's Patent Noiseless Disc Fans," the impeller being 48 inches in diameter, and requires an engine of about 8 horse-power to drive them at a speed of from 800 to 1000 revolutions per minute, when they will discharge at the rate of from 10,000 cubic feet of air per minute, which may be either *pure* air to force into the ship; or by attaching the main trunks as suctions to the central orifices, and opening the discharges into the air shafts to the upper deck, foul air may be abstracted from any part of the system of pipes, or one set might be used to supply fresh air, and the other to abstract an equal amount of vitiated air.

If all the fans are working full together, it would be possible to force into the ship from 50,000 cubic feet of air per minute. The suctions are placed in special air shafts open to the flying-deck, and closed to the rest of the ship, thus ensuring complete isolation from ascending air and gases from the decks and holds below.

The discharges lead into main trunks 22 +15 in area (sectional) all connected with each other, so that the pressure from all the fans will be equalized, or one fan would supply air to the whole system of pipes. One fan may also be used to supply air to the stoke-holes only. They are all provided with stop-valves to prevent the air escaping through a fan that may not be at work.

Sluices are fitted so that each compartment can be shut off in the event of an accident, the same as those below for other services. This arrangement is necessary to meet any emergency, but it is not complete, for suppose the compartment next abaft the engine-room to be cut off, the compartment next abaft that, and the whole after part of the ship would be deprived of ventilation, not at all a desirable state of things under any circumstances.

This might be avoided by having fewer openings into the main trunks, and those fitted with balanced self-acting stop valves, that would open easily to the entering air, but would close to any back pressure. Every supply pipe is fitted with a stop-cock, but it would be a work of time to close them all, and a most uncertain method. The arrangements for the magazines are a case in point. The supply for them is taken from the same branches that serve the screw passages. Suppose the compartment enclosing the screw passage to be flooded, unless every cock in the passage flooded, or those in the magazines be closed, water would undoubtedly pass from the one to the other—a most serious consideration. Some arrangement I think should be introduced, quite self-acting, to prevent a back flow of water through any of the mains, branches, or pipes.

In the magazines where there is no connection with any other compartment, special pipes are introduced leading to the upper deck to carry off the used air.

In the engine department, the ventilation is effected by the same system as described for most wooden ships, viz., diaphragms separating the upward and downward currents, supplemented in the stoke-holes, by eight air-pipes supplied from the main service, and a portion of the hottest air in the upper part compartments is drawn off by tubes carried up through the middle of the funnels, in the centre of which the waste steam pipes are placed; the annular space being a valuable addition no doubt.

In the engine-room there are apertures to be regulated at will in the main trunks, which pass through the *upper* part.

In the screw passages there are pipes from the main service, three two-inch pipes in each.

The temperatures at the trial were, on

deck 55°, engine-room, starboard, 108°, midship 95°, port 107°, stoke-holes, forward 113°, midship 104°, aft 86°; after, forward 90°, midship 112°, aft 114°, and this on a comparatively cold day and half a gale of wind blowing so said the papers.

At the risk of being thought impertinent, I say that in my opinion, none of the provisions in this department are as perfect as they might be. In the engine-room the fresh air is admitted at the *highest* point, just over where you might expect a current of hot air from the cylinders to be battling for escape upwards; the orifices should be carried lower down, to prevent the wings from becoming burning fiery furnaces, though this defect might be remedied or mitigated considerably if a current of cold air could be discharged from the screw passages into that region, as is generally the case in ordinary vessels, most of them having air-shafts carried up by the screw-well to the poop, but here there is a very inadequate supply, there being only three 2-inch pipes in each screw passage.

At the trial the temperature was from ten to fifteen degrees higher at the wings than amidships, though it is at the sides where the cold air is admitted, proving a want of circulation.

In the stoke-holes the air pipes from the mains are led into the bilge, and through stoke-hole plates amidships, at intervals of 7-feet, eight in number, and discharge 18-inch from the plates; a good arrangement so far as the distribution of air is concerned, but I think it would puzzle any one to select a more inconvenient position, taking the duties and comfort of the men on the fires into account, they will be continually knocking their hands, or falling over them. I would suggest at the ends or between the boilers as more suitable places, or at least their being placed close along-side the iron columns, as I believe is the case in the *Sultan*.

There are two funnels and two sets of air spaces divided by diaphragms from the flying deck down into the stoke-hole, ending 9-feet from the plates; as it is fully established that the lower the partition can be brought down the more effective it will be. I think in this case if they were brought a few feet lower it would materially improve the ventilation.

The same remarks apply to the shafts for hoisting ashes, and in addition they would be much safer than at present, for when they are high enough, those on duty are very liable to take severe colds from standing under them, and there is also danger of being brained by falling ash-buckets. A short time ago an engineer passing one was seriously hurt by a bag of coal being dropped upon him. I was under the impression an order was issued at the time for them to be always carried as low as possible.

There are also six downcasts from cowls on the flying deck, leading through the uptake round the funnels to within 9 feet of stoke-hole plates.

The great importance of supplying an efficient system of ventilation for the engine department may be readily appreciated if we consider that more than 100 tons of coal can be burnt in the 24 hours, and that for the effective combustion of these alone no less than thirty-three millions of cubic feet of air is required for the bare chemical equivalent, but in addition to this, we ought to allow as a margin to meet the defects in construction, mismanagement of firing, &c., at least fifty per cent. more. The amount required for ventilation that would pass through the uptakes round the funnels may be taken at perhaps another fifty per cent., giving the enormous total of sixty-six millions of cubic feet, or at the rate of nearly three million cubic feet per hour or forty-six thousand per minute.

I will not attempt to dilate upon the tempting theme that here suggests itself, viz., that we are now speaking of the very vitals of the huge machine, and that the whole well-being of itself and the lives of its officers and crew entirely depend upon a maintenance of perfect efficiency in this department. I am sure there are those present who will do full justice to the subject, and I leave it with confidence in their hands.

Though as I stated the arrangements are simple, in my humble opinion they are far from complete. I will endeavor to give my reasons for thinking so. I told you ventilation may be performed either by abstracting the foul air and allowing the fresh to be supplied by gravitation, or by forcing pure air in, driving the foul air out; the arrangements on board the *Devastation* admit of either system being used simply by reversing the fans, but the latter, or forcing system is evidently intended to be chiefly relied upon, as no provision is made for the free introduction of fresh air by the first named process, except through the skylights

or hatchways, which more than likely have to be closed occasionally.

As the absence of special entrances for fresh air prevents the effective working of one system, so does the absence of special means of escape of foul air and gases, endanger the success of the other: in the one the foul air would of course be extracted, but in the other the fresh air on being forced into the room or compartment, would mix with the foul to a certain extent, especially as carbonic-acid gas settles towards the deck, where the mouths of the supply-pipes are placed. The theory that the air inside would be warmer and lighter, and thus pass upwards before the colder currents, I am afraid would not hold good here, for surrounded by so many tons of iron, I think it not at all unlikely that the outer atmosphere would be of a greater temperature, except perhaps in the vicinity of the engine department, and in that case no one could guarantee that the pure air would not pass out leaving the tainted behind, or at least mingling with it to such an extent as to render the quantity of fresh air necessary to be supplied considerably increased; but to this there must be a limit, for the current would be so strong that it would be unpleasant, and perhaps dangerous to health.

I maintain that to ensure anything like perfect ventilation proper means should be provided for both sides of the operation, ingress, and egress; the present system could be so adapted with comparatively little trouble, by taking one set of fans for forcing fresh air, and the other for abstracting foul. There are two main trunks already, except for the distance through the bunkers, where there is only one, but of course another could be added.

In support of this view of the question, I would suggest that it would be anything but pleasant or healthy to live surrounded by vitiated air, for though you may be sure you are receiving a certain amount of pure air when in your cabin or mess-room, you may be equally certain that outside, in the wings, passages, &c., you will encounter contributions from the many indescribable smells to be met with occasionally in the cleanest ships. The downcast through the engine-room would no doubt take a great quantity of the expelled air in the vicinity of the gratings, but that would not affect to any extent the other parts of the ship. In this opinion I differ from the designers of this system, for the apertures over the engine-room are chiefly relied upon for the exit of expelled air from the greater part of the ship; experience alone will decide this question, which in itself is not of any great importance; it does not matter much which way the air is removed so that it is got rid of.

The small circular hatch over the ward-room is expected to perform the same office for the after part of the ship (a by no means extensive provision, and not a particularly palatable one either to those living in such close proximity to a point), towards which the currents of vitiated air from this part are to be driven.

I noticed there is no special ventilation for the series of w. c's urinals, they are open to the wing passage on the breastwork deck: they are close to the ports in the ship's side, but I think these will as often (certainly when to windward), let in air instead of allowing any escape, so that each time a door opens at the ends of the passage, there will be a rush of foul air into the whole after part of the ship. They should be enclosed, and provided with special means for ample ventilation, independent of any state of wind or weather.

The double-bottoms, as we are all aware, are apt to become the receptacle of dangerous gases, either evolved from the paint with which they are coated, from stagnant water, or if left open, from the setting by gravitation of the heavier gases given out by the many and various chemical actions continually going on in the ship.

To prevent accumulation to any dangerous extent, I would suggest, that periodically, and at no great intervals, they should be swept through by a current of air, either forced by ventilating engines, or if they are not at work, by opening all connecting sluice-valves and apertures at the extreme ends of the different series, and placing the centres in direct communication with the airing stoves in the engine-room or stoke-holes, so that the whole supply of air required for the stoves, should be drawn through the whole series of compartments. This would effectually prevent gas collecting, and in the event of an accident requiring men to enter the double-bottoms, there would be no delay. Even in harbor, when men are painting the double-bottoms, a ventilating fan has to be kept continually at work or the men would be suffocated. The man-hole doors are kept on at sea; if this plan were adopted no inconvenience would be felt from the necessary practice.

Pipes are led from the double-bottoms to the upper deck, to allow the air to escape when water is being admitted to trim the ship; these pipes would serve either for the escape of air when forced in by the fans, or to supply a fresh stock to replace the amount removed by the stoves in the stoke-holes.

Official attention has of late been directed towards alleviating the sufferings of men employed in trimming coals, and arrangements more or less efficient have been introduced for supplying them with fresh and cool air. All those who have in the stern course of duty compassionated the men they were obliged to order into close hot bunkers to toil hard for four long hours, in an atmosphere thick enough to be cut, will hail these innovations with pleasure. It is difficult to appreciate the oppressive and stifling nature of the work performed by these best-abused and worst paid public servants.

Ventilating shafts are now being carried from the coal boxes into the funnel casing. the draught round the funnel causing a strong current of hot air from the upper parts of the bunkers; the supply of fresh air being admitted by the doors in the stoke-holes, which are generally situated in the vicinity of the main downcasts; this is certainly a step in the right direction, but much yet remains to be done to ensure anything approaching effective ventilation; however, we are thankful for the slightest indications of the introduction of a more considerate and liberal policy.

Up to the present time no provision is made in the *Devastation* for ventilating the coal boxes, but I have no doubt a subject of so much importance is only waiting its turn to receive the amount of attention it deserves. A portion of the air intended for the furnaces might be driven through the coal boxes. and the arrangement would afford a means for changing the air when not steaming, to prevent accumulation of gas, a very necessary precaution now that a percentage of north country coal is stowed. Several cases are on record of slight explosions having occurred, which might have originated serious fires.

Some of the more sanguine of our engineers and philanthropists point to the time when bone, muscle, and human life shall be greatly economized, by the introduction of mechanical stoking—may the time speedily arrive—at present, practical men do not see a clear way for the introduction of any such scheme, necessity in the shape of great scarcity in the coal supply, and its accompanying greatly enhanced price may, and most likely will solve the problem, or, a liberal encouragement offered by the government to our scientific men to bestir themselves, would undoubtedly answer the same purpose—it is simply a question of money; at present there is very little inducement for them to engage their time and capital in any such enterprise.

I will conclude with a remark or two upon the management of the ventilating apparatus—

The admission of air is optional in all cases, every supply-pipe being fitted with a stop-cock; the question arises, is it safe to leave it to the discretion of individuals or messes? I imagine it will often be a matter of keen dispute, tastes differ so much in these matters as well as in any other, and who is to decide? What guides are there to assist in regulating a proper supply—how far will temperature help to determine—or have we anything between shivering from excessive draught, and a depressing headache, coupled with a gradual extinguishing of the lights. I am unable to say what arrangements will be made; undoubtedly something clear and definite should be determined upon, and the whole placed under the supervision of a careful, intelligent officer.

IS 772 FOOT POUNDS THE TRUE DYNAMICAL EQUIVALENT OF ONE THERMAL UNIT.

By John Lowe, 1st. Asst. Eng'r. U. S. N.

Written for Van Nostrand's Magazine.

In order that we may easily understand the subject, let us suppose that we have a vessel of indefinite length, whose area is uniformly one square foot. Into this, place one cubic foot of boiling water. Now let us vaporize it.

The water will expand into steam and will occupy a greatly increased volume. This

expansion is resisted by a uniform pressure, for example, the pressure of the atmosphere.

The work then performed in overcoming this resistance, is a multiple of the resisting pressure (p), the area in inches of one square foot (144), and the ratio between the volume (V) of the steam and the volume (v) of the water; water at 39 deg. as usual being taken as unity. The work then is $W=p\left(\frac{V-1}{v}\right)144$

To perform this work heat has been applied which has not been manifested as sensible heat; so that the latent heat alone has performed this work. If then (Y) is the weight of the steam or of the cubic foot of boiling water vaporized, and if (L) is the number of thermal units latent in one pound by weight of steam, then (LY) is the total latent heat, and the dynamical equivalent (D) of one of these is $D=p\left(\frac{V-1}{v}\right)144$

L Y

If there is no fallacy in the foregoing, then the correctness of the formula depends upon the accuracy of the experiments of Regnault and others. If they are incorrect, then this formula is incorrect, but not otherwise.

Let us now give the quantities in the formula, different and corresponding values as in the table. We will find in the last column (D) the values for the dynamical equivalent under those conditions.

p	V	v	L	y	D
10	2373,	1,0359	978,99	60,289	55,85
14.61	1641,5	1,0426	965,7	59,838	57,511
20	1219 7	1,0492	954,38	59,459	58 85
30	826,32	1,0590	938,5	58,901	60,179
40	627,91	1,0668	926,42	58,481	62.47
50	508,29	1,0732	916,58	58,131	63,86
60	428,32	1,0789	908.18	57,817	65,169
70	371.07	1,0840	900.84	57,554	66,36
80	328,08	1,0884	894.27	57.322	67.28
90	294,61	1,0926	888,31	57,101	68,59
100	267,80	1,0964	882,85	56,891	69,74
120	227,56	1,1035	873,09	56,549	71,80

We find then that (D) is much smaller than generally supposed, and also that it is to all appearance a variable and not a constant quantity. The writer cannot explain the fact. For example, friction could not influence the result because it would be reproduced in heat. The only assignable reason is believed to be that the quantities derived from the perimeters above quoted are not rigidly correct. Several reasons might be given for this belief, but as the writer will be obliged to drop the subject for the present for want of time, it would perhaps be best not to advance these reasons until he can be assured of their correctness.

INDIAN HYDRAULIC CONTRIVANCES.

From "Engineering."

In India a large variety of mechanical contrivances of a very simple nature are commonly used for raising water from rivers or wells, or out of foundations of bridges, that are generally unknown to the English engineer. His natural tendency would be to use the appliances best known to him, such as a windlass and bucket, a common pump, a lift and force pump, or a winding-up chain carrying iron vessels; of these, the last only is very well known in India, in a more simple form, as a chain of pots, or a Persian wheel; pumps are purely European in origin, even a windlass is a comparative rarity, and since such things are not always available it often becomes necessary for him to adopt the native means of raising water and to learn what duty may be expected from them. To aid him, or rather to save him needless trouble in measuring and calculating the duty, the following Tables, based upon data originally furnished by M. Lamairesse, of Pondicherry, for Southern India, and in the Roorkee professional papers for Northern India, but modified and put in a form intelligible to the English civil engineer, may be found useful. It merely becomes necessary to explain the meaning of a few of the Indian names of the contrivances, and state the mode in which they are used.

Baling is one of the most primitive methods of raising water, but the English mode of filling and emptying a vessel or a bucket is not in vogue among the natives of India. A large flat dish of wood bark rendered water-tight, or leather stiffened by a frame, has two long cords attached to it at opposite sides, the other two ends of the cords being held by two men, who generally prefer sitting down to their

work, and together allow the dish to dip in the water, nearly fill itself, and then raise it, send it forward with a swing and let it empty itself above; this can be done with a rapid and continuous swinging motion that is sometimes quite surprising. This method is of course only applicable under certain conditions, such as clearing foundations of water, and such cases as allow of sufficient room for the swinging; the lift is seldom more than five feet though sometimes seven feet; but a series of such lifts can be easily adopted.

Machine.	Details.				Work Done.			Power Exerted.
	Lift in feet.	Men.	Oxen	Per Hour No of Lifts.	Cubic Feet Raised.		Gallons per Day of Eight Hours	
					per lift.	per hour		foot-pounds per second.
1. Picotah...	10	2	...	600	.83	498	24,900	8 x10 = 80
2. "	20.5	2	...	300	1.44	432	21,600	6.9x20.5=141
3. "	20.5	2	...	240	1.60	384	19,200	6.2x20.5=127
4. Dal	10	6	...	1320	.33	443	22,150	7.1x10 = 71
5. Mot	11	...	2	44	1.77	78	3,900	1 3x11 = 14
6. "	20	...	2	90	2.00	180	9,000	2.9x20 = 58
7. "	45	...	2	32	1.75	56	2,800	0.9x45 = 40
8. Double mot	22.5	...	2	180	1.32	238	11,900	3.9x22.5= 87
					per min.			
9. Common pump ...	10	1	...	60	7.77	466	23,300	7.4x10 = 74
10. Mot	16	...	2	35	5.81	203	10.150	3.3x16 = 52
11. Baling	5	2	...	1200	.33	400	20,000	6.4x 5 = 32
12. Beam and bucket ...	16	1	...	180	.45	82	4,100	1.3x16 = 20
13. Windlass	4	1	...	84	2.00	168	8,400	2.7x 4 = 11
14. Dal	5	2	...	84	5.00	420	21,000	6.7x 5 = 33
15. Single mot	40	1	2	70	3.00	560	28,000	3 3x40 =132
16. Double mot	40	1	2	85	3.00	255	12,750	4.1x40 =164
17. Single chain of pots ...	40	1	2	168	.75	126	6,300	2.0x40 =160
18. Double chain of pots...	40	1	2	138	2.40	330	16,500	5.3x40 =212
19. Common pump ...	25	4	...	2400	.10	240	12,200	3.9x25 = 97
20. Lift and force pump ...	40	4	...	1440	.20	288	14,400	4.6x40 =184

The beam and bucket, or balance pole, in its various modifications, is also a favorite contrivance for raising water from wells by hand labor; the lever, at one end of which is hung the water vessel, generally a large earthenware pot, is counter-weighted at the other end so as just to allow the force of one man to raise the vessel when full. The lever is often a beam naturally very thick at one end, and requiring only to be carefully hung or supported at the most convenient point for a fulcrum. In Southern India this principle reaches its fullest development in the picotah; where a very large, long tree, or a very large pair of trees bound together, becomes the balance pole, to work which a man walks and runs backwards and forwards along the heavier arm of the lever, stepping off, when necessary, on to a raised stage; for this work special men thoroughly accustomed to it, are absolutely necessary; one managing the vessel, and the other the balancing. The size of these picotahs is sometimes extremely large, and the lift consequently very high.

The dal or jantu is a contrivance for raising water from three feet to six feet high by means of a wooden gutter moving on a pivot, being a lever, or a double lever of the second order; there are several forms of this contrivance; in the simplest, one end of the single gutter is raised by a man with a cord, or lever and cord, until the water runs out of the other end of the gutter into a trench; in the double gutter there is a wooden partition in the gutter immediately above the pivot, and the water runs out through holes on each side of it in the bottom of the gutter into the trench; sometimes these are worked by cords and sometimes by means of the weight of a man and a counterpoise weight at the end of a long lever attached.

The mot is an arrangement worked by oxen; it generally consists in a water vessel made of a complete ox-hide bound on to a wooden ring for an opening, raised and lowered by a cord running over a pulley, fixed immediately above or projecting over the well, the bullocks going down an inclined plane made for the purpose, when dragging up the water vessel or mot, which has to be dragged to one side on arrival above the mouth of the well and emptied by a man. In Southern India there is an improvement on this which dispenses wit

the man for emptying; the lower end of the mot tapers out to a good length, and has a smaller cord attached to it, which, by means of a suitably adjusted catch, causes the mot to empty itself on arriving at the proper height.

The contrivance generally called by Anglo-Indians a Persian wheel, but more properly a chain of pots, is almost identical with that used in Egypt, Nubia, Syria, Abyssinia, known there as the sakia; its advantage is that it will raise water from any depth by means of sufficient animal power. In India it is generally very much of the following description: Two parallel, endless ropes, united to each other by rungs of wood or of rope pass over a vertical wheel and hang down to below the water surface in the well; earthern or leathern vessels are attached to the rungs, which discharge themselves into a trough through the vertical wheel, which is a double framework. Motion is communicated to the axle of this vertical wheel from a vertical shaft of wood that is turned by a pair of bullocks, by means of two wooden wheels working into each other. The upper end of the vertical shaft is kept in position by a very heavy beam or tree, which rests also on two supports, generally mud walls, beyond the sweep of the circle in which the oxen walk. The principle of this rather rude but effective contrivance was doubtless the basis of the double iron chains of pots with brass buckets holding about a gallon each that were used by the Romans, and hence also the remote ancestor of our modern chains of pots having chains of jointed bar iron, skeleton six-spoked or hexagonal wheels, and buckets or iron casks of the most improved form; or, again, somewhat like those used on the Metropolitan District Railway to clear the line of water and worked by steam power.

Referring to the table given, the details of which have been reduced and modified in order to show as much as possible what comparison may be drawn in favor of each machine, it will be noticed that the full amount of work done and power exerted is there given for all cases, under a theoretical condition that never occurs in practice. In each and all of these machines a certain amount of work is wasted by leakage, spilling, faulty construction, or inexactness of form, delay for small repairs, and many other such causes. To obtain anything near the truth, therefore, a coefficient of reduction that is purely empirical must be applied. Some of these coefficients are given in the Roorkee professional papers, others are obtained from other sources; they may, for our purposes in dealing with such rough machines, be applied equally to the work done and the effective power exerted; but, as the latter is the principal object under consideration, we shall reduce the amounts under that head only, which become thus:

Number.	—	Coefficient of Reduction.	Effective Power in Foot-pounds per Second.	Number.	—	Coefficient of Reduction.	Effective Power in Foot-pounds per Second.
1	Picotahs ...	.80	64	11	Baling	.75	24
2			112	12	Beam & Bucket	.80	16
3			101	13	Windlass	.50	5
4	Dal	.70	50	14	Dal	.70	23
5	Mots ...	.70	10	15	Mot	.70	92
6			40	16	Double mot ...	.60	98
7			28	17	Single chain of pots	.55	88
8	Double Mot ...	.60	52	18	Double chain of pots.	.60	127
9	Common pump	.50	37	19	Common pump	.50	48
10	Mot	.70	36	20	Lift and force pump ...	.60	110

These results may not at first sight appear to admit of much comparison being made; certain things are, however, plainly indicated by them, the most marked one being that all such rough hydraulic contrivances used in small lifts involve a great waste of power as well as of water, much intermediate time being lost between the lifts, and the machine itself, when on a large scale, being more properly made and more carefully worked. This is shown most on comparing the effective results of the North Indian beam and bucket (12) with the Southern Indian picotahs (1, 2, 3); in the mots, on the other hand, the favor is on the side of the North Indian, probably from his using an additional man. The chain of pots more exclusively used in Northern India appears to be, under theoretical conditions, the most effective of all these contrivances; the data given is unfortunately too rough to draw any comparison between such contrivances and the common English pump. The foregoing figures may, however, be of use to those unacquainted with Indian contrivances when first called on to deal with them.

ON THE RECENT REACTION OF TASTE IN ENGLISH ARCHITECTURE.*

From "The Architect."

Whatever may be the opinion of those interested in architecture as to the wisdom of the reaction which is the subject of discussion in this conference to-day, there is sufficient evidence of the fact that there has been recently in England a reaction of taste against Gothic architecture towards what is commonly called Queen Anne architecture, a name which, though inadequate and unsatisfactory, is sufficiently intelligible.

But though this style of architecture is a form of classic, the question which engages us to-day is not the often-fought "Battle of the Styles," of which we are all weary. The issue under discussion is different. There is no question on either side as to whether the forms of architecture are to be bound down for ever to the same unalterable proportions, or as to whether we are to use a native style or one imported from Italy. Both those who favor the reaction and those opposed to it admit that Queen Anne architecture violates classic rules; and that it is of native growth as much as Gothic is.

Nor are the combatants the same as in the old well-fought battle of the styles. The peculiarity of the present movement is that the upholders of this form of classic are the same men who have hitherto been devotees of Gothic; who thought it, as I confess I used to think it, an abandonment of principle to use any other style, who practiced it in its severest forms, and even thought Chartres Cathedral a little too late; some of whom, acting as if they thought the monuments of English history ceased to be of value or interest after the sixteenth century, and, regardless even of what used to be thought the respect due to the memory of the dead, have helped to clear out of the old churches of England every vestige of what they considered debased Pagan taste with as much zeal as ever Puritan purged Church of idolatrous images. That these men should have been carried away by what Mr. Ruskin calls "the foul torrent of the Renaissance," and polluted themselves with what another writer calls "the abominations of Sir Christopher Wren," and fallen in love with a style which the upholders of classic and Gothic equally denounced as base, degenerate, and corrupt, seems to require some explanation.

Of the fact there can, I think, be no doubt. There has been an awakening in the minds of some men, who formerly cared nothing for any style but Gothic, to the interest and merit in Queen Anne architecture. One architect told me that, going back after a long absence to the office, where, full of youthful enthusiasm for Gothic, he had served his apprenticeship, he was astonished to find that it contained a most beautiful Georgian staircase, which he at once wished to measure, but which, though he had gone up it every day for five years, he had never before noticed. Another, not an architect, but interested in art, told me that he had lately ben surprised with the beauty of Hampton Court Palace, which on a former visit, some years before, he had found disappointing and uninteresting.

We see also buildings in this style, the work of architects brought up on Gothic.

Nor is the movement confined to architecture. The pre-Raphaelite school of painters have abandoned the purity and restraint with the stiffness and imperfection of Mediævalism, and glory in the fullness of physical life and the richness and freedom of classic ideas.

These are, I believe, true evidences of a reaction in taste. The rise in the price of Queen Anne furniture and chimney-pieces, pounds scarcely buying now what shillings bought a few years ago, is evidence merely that the movement has become fashionable, and consequently in danger of becoming vulgarized.

Some assert that the whole movement is a mere fashion, first started by Dante Rossetti, and imitated by his followers. As well say the Gothic revival was an imitation of Pugin or of Horace Walpole and his Strawberry Hill. Pioneers like these are not causes, but the first results of the causes which move the waves of the world's

*A paper read before the Society of Architects by Mr. J. J. Stevenson.

history. Their distinction lies in being taller than their fellows, and their eyes being the first to catch the beams of the new light that is rising.

In fact the architectural movement in each case is the sequence of a previous religious and literary movement.

As in the new light of French Revolution doctrines, the few vestiges of the Middle Ages which had survived the Renaissance, were passing away, the re-revived in the feeling of the time an appreciation of the glory and chivalry and adventure of the Middle Ages, of their religion also, and subsequently of their art.

In England this reaction to Middle Age ideas has strongly influenced the more imaginative minds; since the time of Sir Walter Scott their religion, poetry and art have been Mediæval. It was a natural and living movement, and for this very reason subject to the law of all living things, change, growth, and development. The feeling grew that there are elements of modern life which not Middle Age chivalry nor asceticism, nor Gothic architecture, were fitted to satisfy. The naturalism and emotionalism, the absence of restraint and conventionality, and also of refinement, began to pall, and men turned, as in the sixteenth century the generation trained in the same Mediæval ideas had turned, for satisfaction of the wants they felt rising in their nature to the treasures of classic literature, to the classic conception of life, glorying in full, healthy, natural outcome, yet moving in measured rhythm, and to the art which is the manifestation and expression of such life.

Minds which had passed through this process found in the forms of Renaissance art, produced under a similar process three centuries before, the expression of their own thoughts and feelings. Correct rigid classic art had no interest for them. They had still too much of the life and freedom of Gothic in their souls to submit to be bound down to ready-made lifeless rules. To classic art in them the infusion of the Gothic spirit gave—what the infusion of Gothic blood had given to the worn-out civilization of the later Roman Empire—new spirit and new life and the hope of higher development.

The springing up of a taste for some form of free classic architecture is therefore not unnatural, but was to be expected in those who had drunk deeply of Gothic. And the form of free classic which thus arose was naturally determined by local conditions. Englishmen working in brick, and using sliding sash windows according to the custom of the land (a custom the necessity of complying with which has ever been a thorn in the side of modern domestic Gothic), found the natural expression of their feelings in the brick architecture of the Restoration, of Queen Anne, and the Georges.

This architecture has neither the exquisite grace and refinement of Greek, nor the romance and high aspirations of Gothic, but it is perhaps not, therefore, the less suited for the common daily wants of English life. It has much to be said for it on practical grounds. Take the ordinary conditions of London building—stock bricks and sliding sash windows. A flat arch of red cut bricks is the cheapest mode of forming the window-head: the red color is naturally carried down the sides of the window, forming a frame; and is used also to emphasize the angles of the building. As the gables rise above the roofs it costs nothing, and gives interest and character to the building, to mould them into curves and sweeps. The appearance of wall surface carried over the openings, which, in Gothic, the tracery and iron bars and reflecting surface of thick stained glass had taught us to appreciate, is obtained by massive wooden frames and sash bars set, where the silly interference of the Building Act does not prevent, almost flush with the walls; while to the rooms inside these thick sash bars give a feeling of enclosure and comfort.

With these simple elements the style is complete, without any expenditure whatever on ornament. Some may say that it is not architecture at all, but mere building. As well say eloquence is impossible without sounding epithets and flowery paragraphs. Such simple building may test to the full an architect's highest faculties—the power of producing harmony and proportion—for there is nothing but harmony and proportion to depend on for the effect. We may, if we have money to spare, get horizontal division of the façade in this style, as in Gothic, by string courses and cornices, and we have the advantage over Gothic

that we can obtain vertical division by pilasters, which, though not constructive, any more than string courses as used in Modern Gothic, have at least as much meaning in a London house as pointed window arches.

Under other conditions some other form of free classic style would naturally prevail; as in Scotland, what is called "Baronial," which, while using classic details, is full of the spirit of Gothic; though the usual modern revival of the style, with its mimicry of fortification at the top and huge undivided plate glass windows at the ground level, expresses rather modern ostentation than the quiet reserved dignity of the old Scotch houses. In a stone country like Derbyshire the old local classic of the district with the windows divided by mullions and transoms is still suitable for modern wants; while in the more important buildings of our towns we may have a wide choice among the numerous forms of free early Renaissance. It is an abuse of words to call all these styles "Queen Anne." The term "Free Classic," or, if it is not a barbarism, "Re-renaissance," would more correctly designate the movement.

The style in all its forms has a merit of truthfulness; it is the outcome of our common modern wants picturesquely expressed. In its mode of working and details it is the common vernacular style in which the British workman has been apprenticed, with some new life from Gothic added. The great mass of dwelling-houses are built now, as in former days, without the aid of architects, and, as the builder, in his own work, is apt to imitate anything new which he sees architects have produced, there is some little hope of his carrying out this style without the painful blunders he, and some architects also, it must be confessed, make in attempting Gothic, of which they do not understand the grammar.

In truth the success of Gothic is with those who loved it one cause of this reaction. Its advocates urged that it was good not only for churches, but for every kind of building; that it ought to become again, as it had once been, the vernacular architecture of the country. The wish has been granted. The nineteenth century has expressed itself in Gothic; and, in gin-palaces, rows of houses built to sell, semi-detached villas, chapels and churches, Gothic, which of old was simple and unpretending, by means of its boasted freedom from restraint has lent itself with fatal facility to the expression of loudness, vulgarity, obtrusiveness, and sensationalism more objectionable far than the dreariest classic of Gower or Wimpole street. *That* may be very dull prose, the other is screeching sensational poetry or Daily Telegraphese.

The account which I have attempted to give of the genesis of the movement explains the fact that it has not extended to churches. In these, Gothic has not the practical difficulties which it encounters in house-building; and although as Dr. Newman says, the architecture of the Jesuit churches, with their untrammeled magnificence, is the true expression of Catholic feeling, Gothic architecture has for English churchmen the strong authority of old custom, and suits better their simpler ritual.

It explains also why those who have been affected by this movement would still design churches, and, if need were, other buildings also, in the Gothic style, which they have not ceased to understand and reverence, though it does not now, on all sides, bound their horizon.

It is much more important that our architecture should be good in whatever style is adopted than that it should be in any particular style.

Nor is it likely that the Queen Anne style in its old form should again become that of our London streets. It is cheering here and there to see old houses blossom out again in fresh red brick angles and white paint on the window frames, which, if done up a few years ago, would have been swathed in the dead-clothes of stucco. Tags and shreds of the style will doubtless appear in speculative builders' houses, and we may even see street rows in it, violating its best characteristic of freedom and spontaneity by repeating the same fantastic gable or the same elaborate porch as many times over as there are houses in the row. But the incompetent meddling of the London Building Act, and the sovereign will of the five or six great noblemen who dictate to Londoners the style of the houses they must live in, compel an autocratic monotony and forbid the characteristic features of the style,

with the picturesqueness and variety which make old towns so charming.

But one thing perhaps from this reaction we may hope for—that the wanton destruction of the old buildings of the style may cease; that the quaint spire of Hampstead Church may still be left to us—that the estate regulations which, on lease renewings, instead of freshening up the cheery old red brick and white window frames of the Bloomsbury houses, has been transforming them into vulgar dismal stucco, may be allowed to cease—that in the district farther west *all* the elegant old balcony railings and pretty wooden tracery of the lunettes above the doors may not give place to coarse cast-iron and plain sheets of glass. We may even, perhaps, see the plate glass removed again and the tracery and small panes restored. And I do not even despair that Mr. Burges himself, who alone almost of the champions of Gothic has been true to his first love for it, and has never fallen away to heathen abominations, may yet come to have such reverence and love for St. Paul's, not only as an historical monument, but as the great work of a great artist, as may make him feel it impossible for him to carry out his proposal of effacing and destroying Wren's design.

RIVER POLLUTION.

From "The Building News."

Mr. W. F. Butler, Assoc., Inst., C. E., read a paper "On the Reports of the Rivers' Pollution Commissioners," before the Civil and Mechanical Engineers' Society, in which he presented a great many items of interest to the sanitary engineer. The paper was exceedingly long, and we therefore cannot do more than give a few brief *excerpta* from it, premising that in it Mr Butler discussed the reports of the Commissioners on the pollution of the Aire and Calder. The important towns of Skipton, Keighley, Bradford, and Leeds, with a population of more than half a million, are situated in the basin of the Aire, while that of the Calder are Todmorden, Halifax, Huddersfield, Dewsbury, and Wakefield, which, with other smaller places, have a population nearly as large. According to the report, Skipton was rather in advance of some other towns in the basin, as the Local Board took every opportunity of substituting water-closets for privies. Some of the sewers of Keighley are described as being 3ft. high, 2ft. wide at the top, and 16in. at the bottom, and covered with flat covers, the only ventilation being by gullies at the street side. The Local Board of Keighley was opposed to the water-closet system, favoring the privy and ash-pit; nevertheless, it was found that sewers were not less necessary than in other towns, and that sewage required purification before being passed into rivers, whether water-closets passed human excreta into the sewers, or privies excluded the solids. At Keighley an instance is recorded in which there were four or five privies under one house, and a visitation of small-pox to the house killed seven out of its nine inhabitants. Bradford, which has a population of upwards of 100,000 inhabitants, is situated on both sides of a small stream called Bradford Beck, about four miles south of the Aire. Bradford Beck, with a drainage area of 14,660 acres, has been polluted to such an extent that to be "as foul as Bradford Beck" is locally tantamount to being more than usually filthy. The Beck receives the whole of the sewage of Bradford, and not only is the stream in great part covered over with buildings, but many proprietors on either side, claiming the soil to the centre of the beck, have placed the outer walls of their buildings in the centre of the stream, so that the water is divided, and (especially during floods) its flow seriously interfered with. Bradford had spent, at the date of the report, about £40,000 in constructing 10,720 yards of main sewers, being a first installment toward a complete system. The diameter of the main outfall sewer is 8ft. 6in., with a fall of 1. in 400, but this is intended to carry off storm waters, and, in fact, to act as a storm overflow, the actual outfall sewer being 4ft. 6in. in diameter, and its cost is stated to be £2 per lineal yard. The ventilation of sewers in Bradford was proposed to be by downspouts and ulti-

mately by chimney shafts, but the Commissioners pointed out that ventilation by downspouts could not be considered effective, as when most required—*i.e.*, during rainfall, the spouts would be charged with down-falling water; and in answer to the objection that open grids in the streets are unpleasant and even dangerous, they point to the fact that many hundreds of miles of London sewers are ventilated on this principle, and also to the known law that the dilution of foul gases is in proportion to the cube of space into which they are discharged. There is this objection, however, to openings in the streets for sewer ventilation—viz., that in northern towns, where the cold is more intense than in London, they are liable to be covered with snow and frozen so as to become closed and useless. It is stated that ventilation by chimney shafts was found to render the air in the sewer sufficiently pure for a distance of 300ft. on either side of the place where the connection was made. At the date of the report there were in Bradford about 26,000 houses, with some 1,500 water-closets, and from 12,000 to 14,000 privies, with 6,000 ash-pits. For cleansing the privies and ash-pits the corporation paid about £2,700 per annum the refuse remaining the property of the contractor, who sold such portions as he could, and tipped the remainder into waste land, or used it to fill up holes, &c. Waterworks, giving a supply of 10,000,000 gallons per diem, had been carried out at a cost of three-quarters of a million. The last place of importance on the Aire, before its junction with the Calder, is Leeds, with a quarter of a million of inhabitants. At the date of the report, Leeds was only partially sewered and drained, but all the sewage from the drained parts of the town was turned into the Aire, as well as vast quantities of liquid refuse from all kinds of manufactures. The river below Leeds is described as so sickening to sight and smell that persons are advised to eat and drink before going near it. In addition to the liquid refuse, enormous quantities of solid refuse, such as engine ashes, house ashes, foundry dross, broken bricks, crockery, &c., were thrown into the river, so that the bed of the river was being gradually raised, to the great injury of surrounding property in time of floods. The principal pollution of the river Calder at Todmorden consisted of solid refuse, both manufacturing and domestic, which was continually cast in. Sewage pollution was not extensive, as the town had no regular system of sewers. Halifax, situated on the Hebble, a tributary of the Calder some miles below Todmorden, had been well sewered, the sewers discharging by one outlet into the Hebble. In size the sewers varied from a 9-inch pipe to stone sewers 5ft. by 3ft. 6in. The sewering of the town, coupled with good water supply, had mainly contributed to reduce the death-rate of Halifax from 34 to 24 per 1,000. Huddersfield, some distance to the south of the Calder, at the junction of the rivers Colne and Holme, was partially sewered and drained, the sewers discharging by five outlets, partly into the Colne and partly into the canal. Dewsbury, just below Huddersfield in the basin, and on the main stream of the Calder, was partially sewered with brick and stone sewers, discharging by six outlets into the river, and ventilated by manholes only. Wakefield, the last town of importance on the Calder, contributed to the contamination of the river by emptying therein not only its sewage, but dye-waste, soap-waste, and every possible kind of pollution, and yet the water supply of the town was mainly drawn from the river below the sewage outlet. The only town of importance on the united streams of the Aire and Calder is Pontefract, which was but partially sewered. The rivers and streams of Yorkshire in their natural state were described as being beautifully clear and pure, as might be inferred from a tradition that the women of Castleford, a town situated at the confluence of the Aire and Calder, were said to preserve their beauty by frequent use of the river water, or, as the old distich has it—

"Castleford lasses must needs be fair,
Washed in the Calder and bathed in the Aire."

The present condition of things is shown in the following lines, which though referring more particularly to Leeds, is more or less applicable to the whole of the towns on the Aire and Calder:—

"The Aire below is doubly dyed and damned;
The air above with lurid smoke is crammed.
The one flows steaming, foul as Charon's Styx;
Its poisonous vapors in the other mix.
These sable twins the murky town invest;
By them the skin's begrimed the lungs oppress'd.
How dear the penalty thus paid for wealth,
Obtained through wasted life and broken health."

An important item requiring the engin-

eer's strict attention and care, is the ventilation of sewers, and in this particular the towns in the Aire and Calder basin seem to be generally deficient. In many cases the rain-water pipes of houses form the only ventilators. The side entrances in some instances are relied upon, although in many cases they are covered with stones and road material. Neither downspouts nor manholes, even if the latter have the usual iron cover, can be considered efficient ventilators, the former being useless when most required, while the latter never allow a free flow of foul air unless the cover is raised. When sewers are not ventilated they transfer fever and other diseases from the lower to the higher parts of the town, as the gases constantly ascend to the highest end of the sewers; and in these cases the people who suffer most are usually those inhabiting houses of the better class, as in these the water-closet is almost universally adopted, and the foul gases are more intimately introduced into the house. As the Commissioners observe, the first requisite for sewering and draining is effectual ventilation, for if this be not attended to, sewering and draining a town may prove anything but a blessing; and they appear to consider that no better plan has been yet devised than that commonly followed in London. Some of the witnesses who were examined before the Commissioners advocated the use of factory or specially-built chimneys as ventilating shafts, and in one instance it was stated that this had been carried out with satisfactory results. But in the case of a system of sewers doubts were expressed as to whether the shafts would draw out the gases for any great distance on either side of the connection. In most cases special shafts would have to be built, for manufacturers would object to any air channels being carried into their chimneys, as each connection would diminish the draught. To ensure upward motion fires must be kept burning, and no air should reach the fire save from the sewers. No reliance could be placed on the unventilated water-trap to prevent foul gases from entering houses. The water would become surcharged with gas, and the gas would be transmitted almost as though there were no intervening water. The unventilated water-trap was a delusion and a snare. Mr. Butler then discussed at some length the fiercely-contested question of "Water-closet *v.* Privy," coming to the conclusion that generally the water-closet was the cleanest, cheapest, and most effectual means that could be devised for the rapid removal of human excreta. The earth-closet system was of course to be preferred to the privy and cesspit, but the water-closet was the only known contrivance which was applicable to large centres of population. Having dealt with the pollution of the Aire and Calder by manufacturing refuse, and shown that it was not only necessary but possible that much, if not all of this refuse, might be purified before being passed into our water courses, Mr. Butler remarked that the common law with regard to river pollution seemed to be that no person or corporation could acquire a right to create a public nuisance, but the persons or corporations could acquire prescriptive rights, by user of twenty years, to pollute streams and occasion nuisances which, while not injurious to health, might cause injury and annoyance to other individuals, so long as a public nuisance was not created. Of course, any person creating a nuisance was open to an action within the twenty years by those who were injured; but this was a very unsatisfactory and expensive process, and uncertain in its results, since the whole proceedings might be upset on some legal quibble having nothing whatever to do with the merits of the case. Besides, neighbors did not like going to law with one another, as it caused ill will and bad feeling, and cases frequently occurred in which persons sold mills and other property rather than quarrel with their neighbors. All this pointed to the urgent need of comprehensive legislation upon the important subject of river pollution. An important aspect of the question was the effect of river pollution upon health. Almost all the towns named in the report on the Aire and Calder exhibited an extremely high death-rate. At Wakefield it was 27.41 per thousand; at Huddersfield, 24.90; at Leeds, 33.80; at Bradford, 28.00; at Skipton, 26.00; at Castleford, 18.00 to 23.00; and at Pontefract, 29.10 As stated in the former paper on the Thames and Lea, it was difficult to trace disease directly to polluted rivers; they caused a general lowering of health among people living near them, rather than any direct sickness. At the same time there were certain types of disease which were seldom absent from their neighborhood. Typhus and typhoid fever

and small-pox were nearly always present, while cholera was ever ready to attack a population already enfeebled by foul air, bad water, damp subsoil, and ill-ventilated and overcrowded dwellings, and so predisposed to its terrible influence. In conclusion, Mr. Butler dealt with the rainfall and water supply of the Aire and Calder district.

WHITWORTH STEEL.

From "Iron."

Sir Joseph Whitworth has lately published an account of his method of casting and rifling steel guns (*Guns and Steel.* By Sir Joseph Whitworth, Bart. London: Longmans & Co.). He states that from the first he was impressed with the superiority of steel as a material for guns, although for a considerable period the difficulty of obtaining that metal in a state sufficiently ductile and at the same time free from air cavities stood in the way. Highly carbonized steel, when cast in small ingots, comes out sound in the greater portion of its bulk; but in larger castings, owing to the irregular cooling and unyielding character of the material, it is liable to crack or become unsound. Experience has, in fact, shown that it is impossible to cast a large gun of highly carbonized steel that can be relied upon as perfectly sound. With a small amount of carbon in its composition, however, steel becomes so ductile that it will elongate under pressure from 30 to 35 per cent. before breaking, and then will not fly in pieces, but only bulge and tear. But again, steel of this description has the defect of being subject to honeycomb during the casting process, owing to the presence of air cells. To obviate this, recourse was had to the application of extreme pressure to the metal, while in the fluid state, a pressure in some cases of as much as twenty tons on the square inch. As a measure of the quantity of air expelled by this process, and the consequent improvement in density and soundness, it is stated, within five minutes after the application of pressure the fluid column will be shortened by an inch and a-half per foot of length, and drawing out and forging develops in a still higher degree the strength of the material. The importance of this invention, not alone to weapons of war, but also to the still more useful implements of peace, need not be dwelt upon. In the single article of railway axles, the failure of which is such a fruitful source of accidents, it must be invaluable. In the construction of steam-boilers, also, the fluid-compressed steel may be substituted for the material at present in use, with the very best results, both in increased efficiency and a diminished liability to collapse.

The gun steel is cast in hollow cylinders, for obvious reasons connected with rapid cooling and more complete exclusion of air, and Sir Joseph gives a very interesting account of the experiments by which, by means of gunpowder, their powers of resistance was tested. A crucial test was the explosion of 1½lb. of R. L G. gunpowder in a cylinder made of Whitworth fluid-compressed steel, with no other escape for the gas generated than a vent one-tenth of an inch in diameter. "The cylinder was a copy of the breech end of a 9-pounder Whitworth muzzle-loading gun, cut off at the trunnion with the projectile screwed in. It is estimated that the consequent strain would be six times greater than that produced if the shot were free to leave the gun. When fired, it recoiled thirty-two inches along the sand, from the rush of gas through the vent, although the weight was 467 lbs. The screw plug was then taken out, and the cylinder was measured both externally and internally, but no alteration had taken place. The vent, however, had been enlarged in diameter, by the rush of gas from one-tenth to two-tenths of an inch." Sir Joseph refers, with evident soreness, to a report by General Lefroy, in his capacity of professional adviser to the Secretary of War, on a similar experiment, in which that official stated that he thought it "not improbable that good cast iron would stand the test shown." This is a good example of the trials which beset an inventor's path, and it is of importance to remark that owing to the incompetence or prejudice of this individual, the conversion of cast iron guns was persevered in after the superiority of the new material had been satisfactorily demonstrated. The Whitworth ductile steel is manufactured in

thirteen qualities, ranging from a tensile strength of forty tons per square inch to one of seventy-two, the ductility at the two extremes, being respectively thirty-two and fourteen per cent.

In 1854, Sir Joseph was called in to assist Lord Hardinge in his endeavors to obtain the best possible rifle with which to arm the British troops. A series of experiments was accordingly commenced, the track of the bullet being traced throughout its entire course and the trajectory recorded, the first result being the construction of the Whitworth small-bore rifle. Sir Joseph commenced a new series of similar experiments in the following year, restricted in this case to the regulation weight of bullet and charge of powder, but unrestricted in every other particular. The barrel of the Whitworth rifle, as here described by its inventor, is thirty-nine inches in length, the interior is hexagonal in section, and, instead of consisting, as in the Enfield, of non-effective bands and partly of grooves, has rifling surfaces which are wholly effective. The rifling turn is much quicker than that of the Enfield rifle, being one turn in twenty inches, and the angular corners of the hexagon are rounded.

The maximum diameter of the bore is .490 of an inch, and the minimum diameter is .451 of an inch. The bullet may be either hexagon or cylindrical; in the latter case it will expand and be drawn into the recesses of the hexagon, and will adapt itself to the curves of the spiral rifle; in the former case, the inclined sides of the hexagon offer no direct resistance to this expansion, which is easily effected. The length of the bullet is three diameters of the bore. The hexagon form of the rifling has several auxiliary advantages. It allows, for example, of the use of a mechanical-fitting bullet of any degree of hardness, even of steel, an advantage obtained under no other mode. Again, however, obstructions were placed in the way by obtuse officials, a committee of officers reporting to the Government that the bore of the Whitworth rifle was too small for use as a military weapon. Ten years afterwards a similarly constituted committee reported to the War Office that the calibre of a breech-loading rifle should be .45 inches, the exact bore recommended by Sir Joseph Whitworth ten years previously, and another committee of officers, at an intermediate period, reported "that the makers of every small-bore rifle having any pretensions to accuracy have copied to the letter the three main elements of success adopted by Mr. Whitworth—viz., diameter of bore, degree of spiral, and large proportion of rifling surface."

Sir Joseph predicts that, as regards heavy artillery, the professional advisers of the Crown will probably require some time before they are able to see that sound ductile steel is the best material for a gun, that the bore for a given height should be made smaller than at present, that the projectile should be lengthened and its rotation increased. "Following past precedent," however, he anticipates that when the improved methods he advocates make due impression on the official mind they will be adopted, his part in first developing them being at the same time forgotten.

For artillery it is of the highest importance to use that form of projectile which is best fitted for penetration. This, as appears from the result of a great many experiments, is the flat-headed form. Shell or shot of this shape are not deflected in passing through water—a most important property when it is considered that armor-plated ships are easily vulnerable below the water-line. The power of penetration of a steel projectile of this shape is prodigious, a 70 pounder muzzle-loading gun, sending such a shot through a four-inch iron plate and nine inches of oak at 200 yards. In the experiments with Whitworth guns of seven-inch and 5½ inch bores at Shoeburyness, against three iron plates, respectively 4½ and five inches thick, backed with eighteen inches of teak, and having an external skin of iron made of $\frac{5}{8}$-inch plate, the whole forming an imitation of a portion of the side of the *Warrior* ironclad, the projectiles, which were steel shells three diameters in length, flat-headed, and fired point blank at 800 yards, penetrated in three out of four trials, through the five-inch plates, and burst in the timber backing. Still more important is the power possessed by flat-headed projectiles of piercing armor-plates at extreme angles, for in actual warfare the projectile rarely impinges on an armor-plate perpendicular to its surface. The smashing effect of a flat-headed projectile is also much greater than that produced by a pointed one. All this is, however, trifling to the effect produced by the larger guns. "In March, 1870, a

nine-inch armor shell, 3½ diameters long, and made of fluid-compressed steel, was fired at a distance of 200 yards, against the War Office shield. The shell weighed 404 lbs., its length was 31½ inches, and the powder-charge was 50 lbs. The shield was composed of three five-inch plates, interlaminated with two five-inch layers of iron concrete, the whole forming a mass twenty-five inches thick. The penetration was 25½ inches, a portion of the rear end of the shell, measuring six inches, was left protruding, but perfect, neither broken nor upset; but remained a most striking illustration, which has never been equalled, of the power of the nine-inch Whitworth gun." Sir Joseph discusses next, at some length, certain subsidiary questions of detail, such as the length of projectiles, the weight to powder-charge, the influence of the length of the gun and of rigidity in the carriage, compares the advantages and disadvantages of his hexagonal shot with the studded projectiles of Palliser, shows the superior economy also of his own method, and concludes with a description of the nine-pounder breech-loading gun and carriage exhibited at South Kensington, in 1872, and of which a public trial was made at Southport, in the same year.

The following challenge was placed upon the gun:

"This gun will be fired on the sands at Southport, Lancashire, the latter end of September. Messrs. Joseph Whitworth and Co. will be glad to compete with any British or foreign gun and carriage of the same weight, for range, accuracy, penetration, and rapidity of firing."

This gun is made of fluid compressed steel, and the breech is closed by a heavy sliding block of the same material, working between two portions of the breech end of the gun, under and over the sliding block, which may be called block guides. The faces of the block guides are grooved with a number of parallel grooves, the upper and lower surfaces of the block being similarly formed, and inclined at a very small angle to a plane perpendicular to the axis of the gun, thus forming a portion of a screw thread, which would be traced upon a cylinder of extremely large radius. These threads constitute what may be called a "straight-line screw," having their sides nearest the muzzle undercut, so that when the heavy strain, resulting from firing the charge comes upon the block, there may be no tendency to force the block guides apart; but, on the contrary, they are more tightly held. The powder chamber is enlarged in diameter and reduced in length, being 2¼ diameters long, and containing a charge of fifty per cent. more powder than the service charge of a muzzle-loader. There is also a slightly enlarged shot chamber to ensure ease in loading. The enlargement of the shot chamber permits of the reduction of the windage in a degree which could not otherwise be attained. In this gun the enlargement is .03 of an inch, the remaining part of the bore having windage .01 of an inch.

The sliding breech block is shaped at the side, so as to form a part of a tube of the same diameter as the powder chamber; the hollowed-out side of the block forms a prolongation of the powder chamber when the breech is open.

For the convenience of loading it is desirable to fit an inner guide into the tubular part, corresponding with the bore of the piece, and similarly rifled, and through this rifled guide piece the projectile passed into the shot chamber. The guide piece is not, however, absolutely necessary, as the gun can be loaded without it, and in all cases it is removed before the powder cartridge is inserted. The breech block is movable horizontally, and the small obliquity of the threads causes it to tighten itself with sufficient force against the rear end of the gun. It is readily moved to and fro, and provides a large amount of bearing surface for resisting the explosion; the bearing surface in this gun being 30.24 inches, which is three times greater than that which supports the vent piece in the service breech-loader of the same calibre. The breech block is worked by means of a rack and pinion, a stud being formed on the back of the breech block, and a weighted hand lever being mounted upon it; on the same stud a pinion is mounted, which gears with a rack fixed upon the lower guide of the breech block. The pinion is worked by the hand lever, the handle and pinion have interlocking projections, allowing, however, the handle some freedom of motion, so that it may be used with a hammer-like action to start the breech block.

The mechanical features of the breech-loader may be recapitulated briefly as follows:

1. A heavy breech piece with a large area of bearing surface.
2. An enlarged diameter of powder chamber.
3. A slightly enlarged shot chamber.
4. A diminished windage in the bore of the gun.

The carriage like the gun is made of "fluid-compressed steel," and has the trail formed by side plates connected at the rear ends by a metal shoe, and at intervals by cross pieces or stays. The bearings in which the trunnion arms rest, are forged solid with the side plates. The axle passes through the side plates immediately beneath the trunnion of the gun, and through a flanged tube, which is fitted and bolted between the side plates, and forms the main stay. The ends of the axle are coned to receive the wheels, which are bushed with brass, and on each end of the axle a screw thread is cut; a nut on this thread, when screwed up binds the wheel tightly between two collars upon the axle, and resists by friction the tendency of the wheels to revolve when the gun recoils on firing. The screws on the axle are right and left handed, whereby the recoil tends to tighten the nuts.

In order to elevate the gun, a forked lever is jointed to the side plates, just below the axle, and this lever at its rear end, carries a trunnion nut, in which a hand-screw works. The screw is carried by a collar provided with studs or trunnions on either side, which are received into a cross piece connecting the two side plates, and secured there by a cap. The forked lever is connected with the breech end of the gun by a rod, which is pin-jointed, both to the lever and to the gun. The

connecting rod has two or more pin-holes in it, and by shifting the pin connecting the rod with the lever from one hole to another, an increased range of elevation is obtained. On either side of the gun metal ammunition boxes are hung, the axle passing through the middle of the box.

By this construction of carriage the gun is brought down very close to the axle, and consequently less strain is thrown upon the frame, the recoil taking place nearly in a straight line.

BAIE VERTE CANAL.

Written for Van Nostrand's Magazine, by THOS. GUERIN.

The government of the Dominion of Canada has in contemplation the construction of a canal through that isthmus which connects New Brunswick and Nova Scotia, a distance of some 20 miles, so as to connect the navigation of the Bay of Fundy with that of the Gulf of St. Lawrence at a place called Baie Verte.

Different engineers, under the authority of the government, have made surveys, and each has devised a different plan which is recommended as being the best to render the canal successful in its functions when completed.

It is admitted that to accommodate the amount of traffic that will be required of this canal, a daily consumption of 12,000,000 cubic feet of water will be required for navigation purposes; and there being no means in the adjoining locality of producing this amount, it is decided that the canal must be so constructed as to make the tides of the Bay of Fundy available for the required supply.

According to tidal observations which were continued at the Bay of Fundy from the middle of the month of August, 1870, to that of January 1871, the datum having been so assumed that the mean level of the sea stood at 71.40 feet, the tides in the Bay of Fundy varied between 85 and 96 feet; while at Baie Verte, from the month of August, 1870, to the month of May, 1871, the tides varied between 71.60 feet and 77.90 feet.

The government within the last two years has published several reports on the proposed construction of this canal; principal among which are two—one of these I shall designate by K; the other by P.

The report K proposes to construct a canal which shall have a high-water surface at an elevation of 92 feet above datum, and low water at 86 feet; thus giving a depth of 6 feet for storing a supply by which to work the canal—the bottom level is to be at an elevation of 70 feet above datum. The canal is to be 100 feet wide at bottom, the slopes 2 to 1: it is to be 16 feet deep—locks 40 by 270 feet; length of summit-reach 12½ miles; length of second reach 7.7 miles.

This plan proposes to fill the summit reach to a level of 92 feet above datum, from the tides of the Bay of Fundy, and by means of those tides and a small lake in the interior, to maintain that level, or prevent the surface from descending below a level of 86 feet.

The plan P has its high-water surface at a level of 88 feet above datum; low water at 85 feet; thus giving a depth of 3 feet for storing a supply. The length of the summit reach is 18½ miles; the bottom level is at an elevation of 69 feet.

To provide for additional storage, plan P proposes to excavate two reservoirs near the terminus at the Bay of Fundy, which we shall designate by A and M.

Reservoir A is to have a surface area of 5,915,000 square feet, and a length of 9,200 feet. Reservoir M is to have an area of 4,775,000 square feet and a length of 21,800 feet.

A channel 260 feet wide and one foot below low-water line of canal will connect each reservoir with the Bay. In each channel a bulk-head is to be constructed with such a number of openings as will in the aggregate in each case make 250 feet in width for the admission of the tide when it rises to the level of low water or 85 feet above datum.

A channel 100 feet wide and 2 feet below low-water line is to connect each reservoir with the canal, and the water is to be delivered over weirs from these two channels into the canal.

It appears to me that questions arise in reference to this proposed canal which have never before occurred in engineering.

In the present case it is necessary that the high and low-water surfaces and the bottom of the canal must be at such eleva-

tions, and the dimensions must be of such magnitude, as to enable the tide to fill the canal to the required level within a reasonable time. It will be necessary to empty the canal occasionally for the purpose of cleaning; and there must be means at hand to fill it speedily again and to maintain its surface at the required level for the purpose of navigation.

The time required to fill a canal or reservoir to a certain height must depend on the elevation of the bottom and on the velocity with which the tide flows into it.

No comparison can be made between the velocity of the tide at sea and its velocity flowing up the bed of a river or through a channel. The horizontal velocity of the tidal wave in the Pacific Ocean is stated to be 1,000 miles an hour and in the Atlantic ocean 700 miles an hour, and yet the depth of the moving tide is insignificant, the tidal wave being only 2½ to 3 feet high.

The general direction of the tidal wave is from east to west, and yet on land it is seen at various places to move from west to east. The Gulf of St. Lawrence and the Bay of Fundy are on the east and west sides of the isthmus through which the proposed canal is to be constructed; they are only about 20 miles apart in this locality; and yet I can bear testimony to the fact, that thetide runs to the east up the beds of streams which empty into the Bay of Fundy, while it runs to the west at the same time from the Gulf of St. Lawrence up the bed of the river Tidnish. It is true that the high water is earlier at the east side of the isthmus than at the west side by about 2h. 30m.; but it takes some six hours to rise, and hence during the remaining 3h. 30m. the tide is running in opposite directions.

From these facts it would be erroneous to suppose that the velocity of the tide at sea is a function of the velocity with which it moves up the bed of a river. The inland velocity of the tide must therefore depend upon the head or height to which the waters are piled on the adjacent lands which obstruct it in its course from the sea; and hence the vertical and horizontal velocity of the tides must be co-ordinates of one another.

Let r = the height to which the tide rises in seconds of time t.

v = the mean horizontal velocity durring the same time.

Then vt = the horizontal distance advanced.

$\frac{r}{vt}$ = the tangent of inclination of the thread of the current thus generated.

The inclination of a current always varies as the square of the velocity, unless the velocity is very small; the section and wetted perimeter being constant. In the present case it is the velocity of the advancing fillet we are in search of. Its section and wetted perimeter are always the same, while the width of the bed is the same—hence $\frac{r}{vt} \propto v^2$; and if t is constant or equal to one hour $r \propto v^3$; hence $v = n \sqrt[3]{r}$ where n is a coefficient which I have determined in the following manner:

There is the bed of a small stream called the river Missiguash, in the vicinity of the proposed canal, at a distance of about 1½ miles from the seashore. On a calm day I caused a length of 4,148 feet to be measured along the bank of this river, and further on, another distance of 13,040 feet was measured along its bank in the same direction. I caused the flowing tide to be watched, and the time to be noted during which the advancing fillet was traversing those latter two distances The time occupied in the first case was 25 minutes, and in the other 1h. 20m.; thus giving a velocity in the former case of 2.76 feet per second, and in the latter of 2.717 feet. I caused the height to which the tide had risen during those two times to be noted by means of gauges. In the first case it amounted to about 3.87 feet; in the second case it amounted to about 11.30 feet; thus r in the one case is nearly 9.30 feet and in the other about 8.50 feet. The cubic roots of these numbers are nearly in the ratio of 2.76 to 2.717; a fact which goes to corroborate the theory first established.

Hence

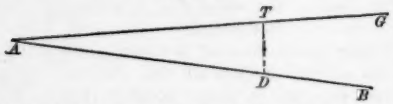
$$\sqrt[3]{\frac{2,717}{8.50}} = n = 1.3313$$

This is an important principle and worthy the attention of engineers who may be engaged on similar duties. It is to be hoped that some gentleman will verify or amend this coefficient in some other locality.

It may perhaps be objected that the value of n, thus obtained from the movement of the tide up the bed of a river or inclined plane, will be inapplicable in de-

termining the velocity, while moving along the bed of a horizontal canal.

FIG. 1.

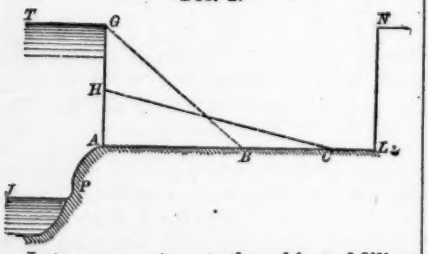


Let A B represent the bed of the canal; A G that of the river; suppose A D to be the velocity along A B, D T being drawn perpendicular, A T will represent the velocity in ascending A G. That is to say; if radius represent the velocity of the tide in moving in the horizontal bed, the cosine of the inclination will represent the velocity up an inclined plane.

I have ascertained the inclination of the bed of the Missiguash by taking cross sections in a few places, and connecting those levels with the datum of the survey. The inclination thus obtained gives an angle whose tangent = .00076.

This angle is so small that the cosine may be considered equal to the radius; hence there is no difference between the velocity of the tide moving up the bed of the river Missiguash, and that of the same tide moving in the horizontal bed of a canal.

FIG. 2.



Let us now return to the subject of filling a canal or reservoir from tide water.

Let A L N G be the summit reach of the canal or reservoir, and A C the entrance gate through which the tide water is admitted: J P being the level of ebb or low tide, and T G that of flood or high tide.

Let us suppose that while the tide was rising the distance A G, it advanced in the canal the distance A B: then the surface of the water, at the end of the first tide will be indicated by the line G B.

While the tide is at the level T G, or high ide, the gate A G is closed, and the water will commence to descend from G, and advance beyond B. Let us suppose that, during a given time, it has fallen the distance G H, and advanced the distance B C; then the line G B will conform to H C.

Let x = G H and y = B C;

t = Time in seconds of falling the distance x, or advancing distance y;

v = horizontal velocity of tide when it acquires the position A G B, and

v' = when it acquires the position A H C;

v'' = mean velocity while advancing along B C;

$$v'' = \frac{v+v'}{2}$$

a = A G = the distance the tide has risen from the moment it commences to enter the canal until it reaches flood or high tide;

b = A B = horizontal distance advanced. in the same time.

Now

$$v : v' :: \sqrt{\frac{a}{b}} : \sqrt{\frac{a-x}{b+y}} \text{ and } v' = v\sqrt{\frac{ab-bx}{ab+ay}}$$

$$v'' = \frac{v}{2} + \frac{v'}{2}\sqrt{\frac{ab-bx}{ab+ay}}$$

and multiplying by t we get

$$\frac{tv}{2} + \frac{tv'}{2}\sqrt{\frac{ab\ \ bx}{ab+ay}} = y \ldots\ldots\ldots [1].$$

Again, let w = width of canal at bottom;

n = ratio of side slopes;

a = depth, as before.

Then the quantity of water received by the summit-reach from one tide will be

$$\left(\frac{a\,w}{2} + \frac{a^2\,n}{3}\right) \times b$$

When G shall have descended to H (Fig. 2): then a becomes $a-x$, and b becomes $b-y$. We then have

$$\left(\frac{w}{2} + \frac{a\,n}{3}\right) a\,b = \left(\frac{w}{2} + \frac{a-x}{3} \times n\right)(a-x)(b+y \quad [2].$$

From these two equations, when any one of the quantities x, y, t is given, the other two can be found.

Considering the movement of the tide within the summit-reach of the canal, it is manifest that, when the reach is long, as in the present instance, the quantity of water poured into it by one tide, cannot have come to a level before the next succeeding tide commences to enter the canal.

Let us suppose that H, Fig. 2, is the point where the next tide commences to enter; then the time occupied in flowing into the canal is limited to the time the tide takes to rise the distance H G.

Let g = entire rise of tide = distance J T; or difference of level between high and low tide;

c = mean vertical velocity of tide per second, during ebb and flood.

Then $\frac{2g-x}{c}$ = time elapsed from previous high tide until the water commences again to enter the canal = t in seconds.

Equation 1 now becomes

$$\frac{(2g-x)v}{2c} \times \left(1 + \sqrt{\frac{ab-bx}{ab+ay}}\right) = y \ldots . [1_a].$$

From equations 1a and 2 we obtain x and y. We are thus enabled to ascertain the elevation at which every tide commences to enter the summit-reach; also the distance each tide has advanced, and the distance fallen from H towards A before the next succeeding tide or third tide commences to enter, etc.

It must be observed that w represents the width of opening of the canal, always at the level of the point H. It is only at the entrance of the first tide that w will represent the width of the bottom of the canal—similarly, a will represent the distance A G only at the first tide; it will represent H G afterwards.

Applying the above formulas to the plan K, I find that without using any water for navigation, the canal could not be filled to an elevation of 92 feet by the tides of the Bay of Fundy, from August, 1870, to January, 1871.

Let us admit that the summit-reach of the canal, according to plan P, is filled up to the required elevation of 88 feet above datum, having 3 feet in depth of water stored in the canal and reservoirs, thus holding a quantity of 81,000,000 cubic feet in reserve to be used as required; let us see whether the canal will remain navigable or preserve its lower elevation of 85 feet and at the same time afford 12,000,000 cubic feet per diem, or 6,000,000 cubic feet between each tide for navigation purposes. The canal and reservoirs have a horizontal area of 27,000,000 square feet.

Let us take the month of October, 1870, and admit that on the 12th day of that month the canal and reservoirs were full to the required level of 88 feet above datum; and that each 12 hours 6,000,000 cubic feet were drawn for navigation. Let us take advantage of every tide, and accordingly find the value of x, from equations 1^a and 2.

I shall admit that, during three tides, the volume supplied by the first of the three had come to a level in the reservoirs before the third tide entered; a circumstance which is not strictly the case; and has a tendency to show that the head, and consequently the volume of water, flowing into the reservoirs, are greater than they really are; thus representing the level of the canal above its actual elevation. However, I concede this allowance, because the calculations that would be required to ascertain the quantity fallen until the entrance of the third tide, etc., are long and tedious, and my time is limited, but the question of the efficacy of the reservoirs shall be fully settled, although conceding to them those advantages.

In the annexed table, the elevations above datums of the tides of the Bay of Fundy are given as they had been registered each day. The tides which occurred at night are intercalated.

The letters A and M refer to the reservoirs already referred to. The rest of the table explains itself.

It may be seen that on October, 19th, the elevation of the surface of the canal would be such that it could not afford the necessary quantity for navigation, and on the day following it sinks below the required level.

Table showing the elevation of Reservoirs A. and M. at the moment of entrance of each tide: also the elevation of the canal at the same time.

October 1870.	Elevation of Tide.	Elevation of Reservoirs at moment of entrance of Tide.		Values of X.		Elevation of Canal.
		A.	M.	A.	M.	
12	89.95	88.000	88.000	....	....	88.000
13	88.95	87.778	87.778	....	....	87.778
13	88.65	87.718	87.719	1.050	1.049	87.596
14	88.40	87.489	87.489	.844	.844	87.491
14	88.10	87.290	87.290	.825	.825	87.304
15	87.40	87.069	87.069	.735	.735	89.934
15	86.70	86.791	86.791	.314	.314	86.774
16	86.00	86.552	86.552	....	....	86.552
16	85.50	86.330	86.330	....	....	86.330
17	85.00	86.108	86.108	....	....	86.108
17	85.00	85.885	85.885	....	....	85.885
18	85.30	85.663	85.673	....	....	85 663
18	85.70	85.441	85.441	....	....	85.441
19	86.00	85.234	85.234	.246	.246	85.221
18	86.20	85.077	85.077	.697	.697	85.019*
20	86.40	84.929	84.928	1.009	1.008	84.815
20	87.10	....	....	....	....	.....
21	87.80	....	....	....	....	.....
21	88.80	....	....	....	....	.....

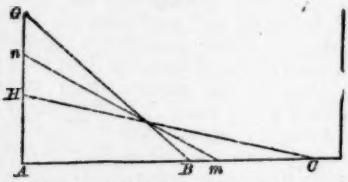
In calculating the quantities in the above table it may be remembered that I have

*Here the supply fails to be effective, and will continue to fail for several tides.

taken the mean velocity while moving over y, equal to an arithmetical mean between the velocity v and v' at the commencement and end of y.

Although this appears quite reasonable, yet let us ascertain the actual value of this mean velocity.

FIG. 3.



Let A C be the bottom of the canal or reservoir, and A G the gate, as before.

Let r = mean vertical velocity in falling the distance G H or x;

z = mean horizontal velocity in moving over B C or y:

t = time in seconds of describing x or y:

G $n = dx$, and B $m = dy$:

v = velocity at B, as before.

Then we get

$v\sqrt{\frac{a-dx}{b+dy}}\times\frac{b}{a}=$ velocity at the point m, and this may be considered the velocity with which dy is described. Hence

$$dt\,v\sqrt{\frac{a-dx}{b+dy}}\times\frac{b}{a}=dy=z\,dt,\text{ and}$$

$$v\sqrt{\frac{a-dx}{b+dy}}\times\frac{b}{y}=z.\text{ Hence}$$

$$tv\sqrt{\frac{a-dx}{b+dy}}\times\frac{b}{a}=y\text{ and}$$

$$a\,b\,t^2\,v^2-b\,t^2\,v^2\,dx=a\,b\,y^2+a\,y^2\,dy.$$

Substitute the value of dx, and there results

$$a\,b\,t^2\,x^2-b\,v^2\,t^2\,r\,dt=a\,b\,y^2+a\,y^2\,dy.$$

Integrate—substitute t^2z^2 for y^2, divide by t^2, and substitute x for $r\,t$, there results

$$z=v\sqrt{\frac{b}{a}\left(\frac{a-\frac{1}{2}x}{b+\frac{1}{2}y}\right)}$$

In the calculations above referred to, v'' gives a larger value for the mean velocity than z: consequently the efficiency of the reservoirs will be worse than it is represented in the above table.

Using the value of z, instead of v'', the forgoing equations become

$$tv\sqrt{\frac{b}{a}\left(\frac{a-\frac{1}{2}x}{b+\frac{1}{2}y}\right)}=y\ldots\ldots\ldots\text{N° 1}$$

$$\frac{2g-x}{c}\sqrt{\frac{b}{a}\left(\frac{a-\frac{1}{2}x}{b+\frac{1}{2}y}\right)}=y\ldots\ldots\ldots\text{N° 1a}$$

$$\left(\frac{w}{2}+\frac{a\,n}{3}\right)a\,b=\left(\frac{w}{2}+\frac{a-x}{3}\times n\right)\times\sqrt{a-n}\times\sqrt{b+y}\ldots\ldots\ldots\text{N° 2}$$

THE CALCULATION OF STRAINS IN TRUSSES WITH INCLINED AND CURVED CHORDS, BY MEANS OF DIAGRAMS.

By E SHERMAN GOULD, C. E.

Written for Van Nostrand's Engineering Magazine.

In trusses with horizontal chords, all strains are transmitted to the abutments through the web members alone, but in the case of such trusses as roof principals, bow-string girders, etc., the chords, being inclined, sustain a portion of the vertical strains, which they convey to the abutments. The calculation of this class of trusses becomes, therefore, more complicated than that of the horizontal systems, and the simplest and surest method of solving their strains is probably that of *diagraming*, that is by the graphic application of the resolution of forces. A certain amount of practice is necessary to enable the student to obtain accurate results by the graphic process of calculation, but when the principle of the method is understood, and the proper degree of manual dexterity acquired, he will find himself in command of resources which permit him to approach all problems of bridge-strains with a confidence that no purely analytical method can give. No mistake is possible, except through carelessness; every force is represented on his draft, in direction and magnitude, and its pathway through the various members of his structure clearly indicated. There are no formulas to remember, and no tables to consult: a scale, straight-edge, triangle, pencil, and a sheet of drawing paper are all that are necessary to solve the most intricate problem which can present itself.

At first it might appear that this method was deficient in accuracy. The student will soon perceive that a slight change in the position of his straight-edge will often produce a difference of several tons in the

strain upon certain members of his structure, and if he is working on a long and complicated truss, he will find it impossible to draft the strains twice alike, the differences being greater or less according to his skill in handling his instruments. He may be tempted therefore to fear that he is employing very clumsy means to arrive at results requiring great accuracy, and be ready to resign the graphic method for any other which promises more mathematical certainty. A little consideration, however, will convince him that this seeming defect is in reality one of the greatest recommendations of the system. The changes of strain which the slightest deviation in the lines of his draft bring about, will reveal to him what is likely to occur in the actual structure, and teach him one of the most important lessons of practical mechanics, namely, the impossibility of reducing static strains to a mathematical certainty. Mons. Claudel, one of the first French authorities on construction, says in his "Pratique de l'art de Construire," in speaking of de-centreing arches—"no "matter how well the equilibrium may have "been calculated, no matter with what "pains all the properties of the materials, "all imaginable accidents, may have been "studied, we may rest assured that at the "moment of abandoning an arch to itself, "the forces of nature will establish a dif-"ferent equilibrium from that calculated "upon, although it may very nearly ap-"proach it, and in many cases differ only "in a degree quite inappreciable to our "senses." If this be true of an arch of masonry, each voussoir of which has been exactly dressed to the templets, and which is subjected only to the gradually applied strain of a permanent weight, to how much greater an extent will it hold good of a structure like a railroad bridge, over which a constantly varying load is drawn at a speed of 20 or even more feet per second? It is probable, in view of unavoidable imperfections of workmanship, the difficulty of keeping all the members of a bridge in actual bearing, and the manner in which a portion—often the greater portion—of the load is suddenly applied and withdrawn, that the roughest draft, in which any pretension is made to preserve the given dimensions, approaches more nearly the theoretical lines of pressure, than do the strains which actually find their way through the structure when it is doing its regular work. I do not wish to be understood as advocating therefore, slovenly and careless work—that would be only making confusion worse confounded—but I do wish to strongly impress upon the student that the strict results which a careful calculation gives him, are only true so long as every member of his truss is in perfect bearing, and *only* in bearing, and so long as the line of pressure passes through the centre of the joints. These are conditions never realized in practice, and considerable allowance must be made, particularly in bow-strings, for variation in the lines of pressure from causes which cannot be reckoned up.

I will now give a few examples of the method of working out strains by means of diagrams, in the hope of inducing students to perfect themselves in this very valuable and useful method. In drawing the diagrams the larger the scale the better, consistently with keeping the draft within reasonable limits. The following examples have been mostly worked out on a scale of five feet to the inch, and five tons to the inch.

These scales are amply sufficient in most cases, and are frequently larger that can be conveniently employed.

FIG. 1.

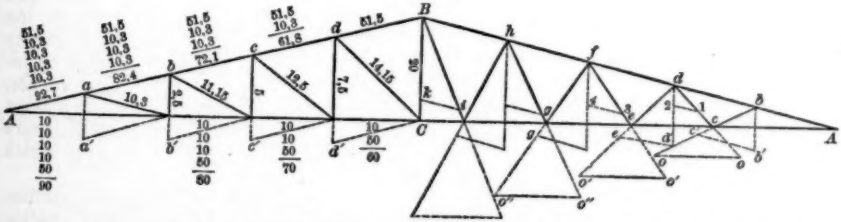


Fig. 1 is a roof principal with a horizontal bottom chord. The span is 100 feet rise, 12.5. It sustains a permanent and equally distributed load, equivalent to five tons on each apex of the bracing. The left hand half represents a system of verti-

cal ties and diagonal struts; the right hand, a system in which both ties and struts are inclined. In the left hand figure, the end panels of the lower chor are 20 feet in length, and the rest 10 feet each. In the right hand figure, the end panels are 15 feet, and the rest 10. In both figures, the upper chord is divided in equal panel lengths.

Let us first take the left hand figure, as the simplest. Mr. Stoney's method of diagraming roofs, is to take the reaction of the abutment and work it along to the centre, adding the different weights as they occur. This method always gives correct results; is applicable to all cases, and should be resorted to when there is the least uncertainty respecting the strains. It has the practical disadvantage, however, of carrying the total strains through the whole calculation, and the strain-lines get very long and inconvenient. Other methods may frequently be employed which give the strains in detail, the totals being obtained by addition. These methods permit the use of a much larger scale for the strains, and are generally of a handier application. We shall work out the present example in the following way. Apex a bears a weight of five tons. This weight is sustained by diagonal a and Aa. Draw $aa' =$ five tons. From a' draw a line parallel to AB. Its intersection with diagonal a (or a produced,) gives the strain on diagonal $a =$ 10.30 tons, and an equal strain on Aa. Both of these strains are compressive. The foot of a resting on the lower chord gives a vertical strain $= 2.5$ tons on vertical b, and a horizontal strain $= 10$ tons through the first panel length of the lower chord. These strains are tensile. The vertical tie transmits its strain to apex b, where it is augmented by the weight of five tons resting on b. Total, 7.5 tons, which draw to scale in bb'. This strain is sustained by diagonal b and Ab. From b' draw a line parallel to AB intersecting diagonal b. This shows a compressive strain of 11.15 tons on b, and one of 10.30 tons on Ab. This must be added to the 10.30 tons already on Aa, making so far, a strain of 20.60 tons on Aa. Diagonal b gives a vertical tensile strain $=$ five tons on vertical c, and a horizontal tension $= 10$ tons on the second panel length of the lower chord. This, added to the 10 tons already on the first panel, gives so far a strain of 20 tons upon that panel. Proceeding in the same manner, we get compressive strains on diagonals c and d of 12.50 and 14.15 tons respectively, and increments of 10.30 tons each for upper panel lengths cb and cd. Tension of 7.5 tons on vertical d, and increments of 10 tons each on the 3d and 4th lower panel lengths. Arriving at the centre, we find a tensile strain of 10 tons on vertical B, which must be doubled, since it receives the same from the strut on the other side. It now remains to determine the compression in upper panel length dB, and the tension in the corresponding lower panel length. Diagonal d transmits, as we have seen, 10 tons to apex B. The weight of B transmits its half, or 2.5 tons to the left abutment, through AB. The total strain traveling through AB is therefore 12.50 tons. Draw BC 12.50 tons. The strain in $AB = 51.5$ tons and in AC, 50 tons. Adding the compressive strains already found, we have, in Bd, 51.5 tons; in dc, 61.8 tons; in cb, 72.1 tons; in ba, 82.4 tons, and in aA, 92.70 tons. In like manner we have, in the corresponding lower panel lengths, $50+10 = 60$ tons; 70 tons; 80 tons and 90 tons.

In the above example the scale and dimensions are such, that the strains happen to be represented by the lengths of the members themselves; that is, the strain throughout AB is represented by AB itself, that in AC by AC itself, the strains in the diagonals by their own lengths, and the strain in each vertical by the length of the vertical preceding it. The panel increments are also represented by the panel lengths.

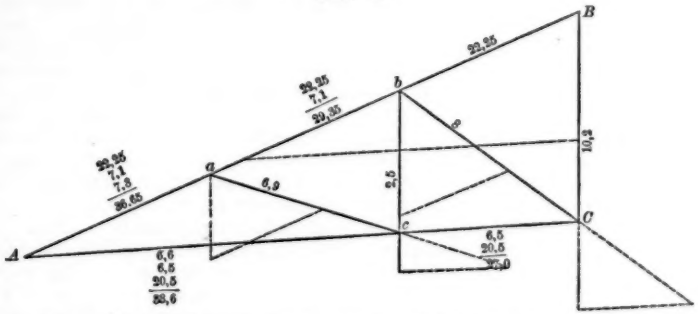
The right hand side of the figure shows the half of a truss of the same dimensions and loading, but with a different system of bracing. It is rather more complicated, but admits of a neat solution. From b, draw $bb' = 5$ tons. This weight is borne by panel length Ab and strut bc. Draw $b'c'$ parallel to AB. The strain on Ab is represented by $b'c' = 6.7$ tons, and that on bc by $bc' = 7.3$ tons. From c, draw co (on bc produced) $= bc' = 7.3$ tons. Draw oo parallel to Ac. Produce dc till it intersects oo. Then $co = 4.8$ tons $=$ tension on dc, and $oo = 10$ tons tension in cA from weight on b. From d, on dc, draw $d1 =$ 4.8 tons, and from 1 draw 1.2, parallel to AB, intersecting a perpendicular dropped from d. Then $1,2 = 3.5$ tons $=$ strain (compression) on db from tie dc, and $d2 = 2.5$ tons $=$ vertical strain of same tie on db and

de. There is also a weight of 5 tons on *d*, which lay off from $2=2d'$. From *d'*, draw *d'e'* parallel to *AB*, intersecting *de* produced. Then $d'e'=6.2$ tons = compression in *db* from vertical strain above mentioned, and $de'=8.5$ tons = compression on strut *de*.

NOTE.—This construction may puzzle the student for a moment, for it may appear as if the strain on *db* from tie *dc*, was taken twice. If however he lays off, as before, *d*1—4.8 tons, and from *d* lays off 5 tons on the perpendicular *dd'*, and takes the resultant of those two forces, and then resolves them along *db* and *de*, he will obtain the result already found. The method I have used makes the action of the last tie *Bi* rather plainer than when the forces are combined, as just described, which is my reason for employing it.

From *e*, lay off $eo'=de'$, draw $o'o'$ parallel to *AC*, produce *fe* to *oo'*, then $eo'=7.2$ tons = tension on *fe*, and $o'o'=10$ tons = tension on *ec* from weights on *d* and *b*. Proceeding thus, we get 10.4 tons and 12.5 tons compression on struts *fg* and *hi*, and 9.7 tons and 12 tons tension on ties *hg* and *Bi*, with increments of 10 tons and 10.2 tons compression through *fd* and *hf*, and increments of 10 tons each through corresponding panels of lower chord. The vertical strain on *B* from tie $Bi=10$ tons, and half the weight on $B=2.5$ tons, also passes through *BA* to the right abutment. Total 12.5 tons, which lay off in *BC*, obtaining compression = 51.5 tons through *AB*, and 50 tons tension through *AC*. But *AB* sustains also 4.6 tons from tie *Bi*, making total strain of 56.1 tons. Adding the increments together we get finally compressions of 56.1 tons; 66.35 tons; 76.35 tons; 86 tons, and 92.7 tons respectively in *Bh*, *hf*, *fd*, *db* and *bA*, and tensions of 50 tons, 60 tons, 70 tons, 80 tons and 90 tons in the lower chord panels.

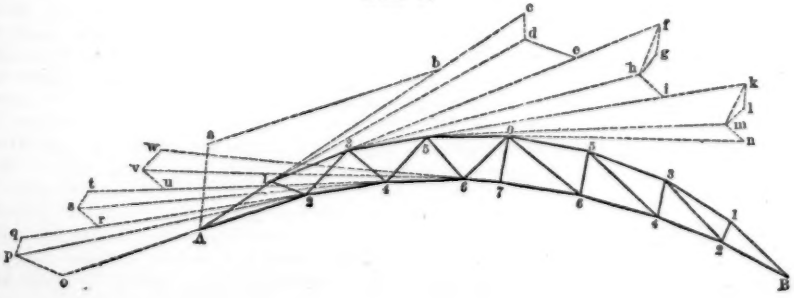
FIG. 2.



When the lower chord is inclined, the same method is applicable. Fig. 2 shows half of a roof principal in which the upper chord or rafter has a rise of 1 in 2.25, and the lower chord, or main tie, a rise of 1 in 15. Each apex being supposed to sustain a weight of five tons, the strains in every member are shown on the figure.

In the very graceful "bent girders" of which Mr. Stoney gives examples on pages 127 and 130 of his first volume, the system of calculation which we have been using is no longer applicable. The strains must be worked out from the reaction of the abutments. As this style of girder offers a good example of the method mentioned, I will give the full work in the case of a roof principal, Fig. 3, 80 feet span, rise of top

FIG. 3.



chord 16 feet ditto, bottom 10 feet. The radius of the upper chord=85 feet, that of the lower, 58 feet. The figure shows two different systems of bracing; let us first consider that shown in the left hand half. The upper chord is divided into equal panels; in the lower chord all the panels are equal except the first, which are 1½ times the length of the others. The load is supposed to be of 8 tons which is equivalent to 1 ton per apex. Half of the entire weight, *i.e.* 4 tons, is borne by each abutment, but in our calculations we count only 3.5 tons as the reaction of the abutment, that is, half the weight on the apexes only, for the other ton being borne by the abutments directly, is immediately annulled, and need not be taken into the account.

The process of calculation is as follows: draw *Aa* perpendicular to the line joining the ends of the truss,=3.5 tons. Draw *ab* parallel to *A*2, and produce *A*1 till the two lines intersect. The reaction of the abutment *Aa* is thus resolved into its components through *A*1 and *A*2, and gives the strain *Ab*=12.3 tons=compression in *A*1, and *ab*=10.4 tons,=tension in *A*2. From apex 1, take 1*c* on *Ab* produced=12.3 tons, and from *c* draw *cd* perpendicularly, =1 ton=weight on apex 1. Then 1*d*=resultant of this weight and the strain in *A*1, which passes through 1, 2 and 1, 3. Produce 1, 3 in 1,*f*, and draw *de* parallel to 1.2. till it intersects 1,*f* in *e*. Then 1.*e*=13.5 tons=compression in 1.3, and *de*=2.4 tons=tension in 1.2.

NOTE.—Care must be taken in these diagrams to distinguish between compressive and tensile strains. The direction of the force, or of the resultant of the forces, furnishes the necessary indication. Thus, the resultant 1*d*, passing *outside* of the two members 1, 3 and 1, 2, and acting in the direction of their opening, exerts compression on the member (1,3) nearest to it, and tension on that (1,2) farthest from it. It acts precisely like a weight suspended from a crane, compressing the *jib* (1,3) and drawing the *tie* (1,2). If acting in the contrary direction, *i. e.* towards the abutment *A*, the resultant would exercise contrary strains on the two members. Did the resultant pass *between* the two members, acting toward their opening, it would compress them both, and if acting in the contrary direction, would strain them both in tension.

From 2, lay off 2,*o* on *A*2 produced=10.4 tons, and from *o* draw *op*=2.4 tons, parallel to 1,2. Then 2*p* is the resultant of forces in *A*2, and 1.2 acting in tension on 2, 4 and 2, 3. Draw *pq* parallel to 2,3 and produce 2, 4 till it intersects with *pq* at *q*. Then 2,*q*=11.7 tons=tension in 2,4, and *pq*=1.05 ton=tension in 2,3. On 1,3 produced, lay off 3*f*=1,*e*=13.5 tons; from *f* draw perpendicular *fg*=1 ton=weight on apex 3, and from *g* draw *gh* parallel to 2,3 =1.05 ton. Then 3*h* is the resultant of the strain in 1,3, the weight on apex 3, and the strain on 2,3, which all meet at apex 3. This final resultant is resolved into its components in 3, 5 and 3, 4, by drawing *hi* parallel to 3, 4 and producing 3, 5 to the point of intersection *i*. Then 3*i*=13.1 tons =compression in 3, 5, and *hi*=1.36 ton=tension in 3, 4. The tension in 4, 6=12.2 tons, and that in 4,5=0.91 ton is then found as before, and the compression in 5.0=12.9 tons, and tension in 5.6=1.04 tons. Finally, the tensions in 6, 7=12.2 tons, and in 6,*o*=1 ton are found, as before. In practice it is unnecessary to actually draw the lines representing the resultants.

The strains in the members of a principal, trussed as shown in the right hand half of the figure, are solved in the same manner. In this system, the diagonals act as struts, and sustain compression. Under the same loading as assumed for the preceding case, we have compressions of 13.7 tons; 12.7 tons; 12.6 tons, and 12.6 tons on *B*1; 1,3; 3, 5, and 5,0 respectively; compressions of 0.6 tons; 0.45 tons, and 0.2 tons on 2, 3, 4,5, and 6,0 respectively; tensions of 11.8 tons; 12.3 tons: 12.6 tons, and 12.7 tons on *B*2; 2, 4; 4,6, and 6,7 respectively; and tensions of 1.75 tons; 1.65 tons; 1.7 tons, and 1.4 tons, on 1,2; 3,4; 5,6, and 0.7 respectively.

It will be noticed that in these and the preceding examples, the strains in the top chord, diminish from the abutments towards the centre, and those in the bracing augment in the same direction, contrary to what obtains in straight girders. This is because a part of the shearing strain passes through the chords, when inclined, instead of being transmitted wholly through the bracing, as is the case when they are horizontal.

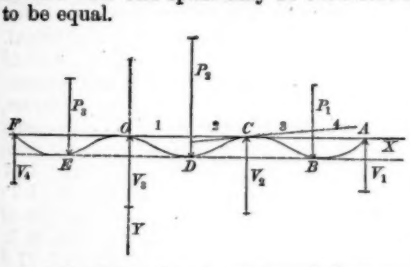
THEORETIC DISCUSSION OF TWO EXPERIMENTS ON THE DEFLECTION OF BEAMS.

By H. T. EDDY, C. E., Ph. D., Cincinnati, O.

Upon page 370, Vol. VII. of this magazine are the results of two "Experiments on the Deflection of Continuous Beams Supported at Equidistant Points," it being a paper read before the American Society of Civil Engineers, by J. B. Francis,

C. E. It is proposed in this article to discuss the theory of a beam supported at three equidistant points, and to show that the results of the above-mentioned experiments agree much more closely with Navier's theory of flexure than the remarks of the experimenter would lead us to suppose.

The beams experimented on were wrought iron bars 12 feet $2\frac{3}{4}$ inches long, supported upon 4 knife edges placed 4 feet asunder and in the same horizontal line. They were loaded at the points midway between the points of support, the weight $P_2 = 82.84$ lbs. being at the centre of the middle span, and the weight $P_1 = 52$ lbs., being at the centre of the end spans in each case, when it was found that the deflection of the middle span differed from the mean deflection of the end spans only .001 inches, *i. e.* the deflection of the middle and end spans may be considered to be equal.



Let the figure be an exaggerated representation of the neutral axis of the beam, take OX and OY as axes (y being positive downwards).

Let OC = CA = $2a$ and let P = weight of the beam per inch of length.

Take the moments of the forces acting about any point in curve (1) or OD.

$$\therefore \text{E I}\frac{d^2y}{dx^2} = P_1(3a-x) + P_2(a-x) + \frac{p}{2}(4a-x)^2 - V_1(4a-x) - V_2(2a-x) \ldots\ldots (a_1)$$

Take the moments about any point in curve (2), or DC.

$$\therefore \text{E I}\frac{d^2y}{dx^2} = P_1(3a-x) + \frac{p}{2}(4a-x^2) - V_1(4a-x) - V_2(2a-x) \ldots (a_2)$$

Take the moments about any point in curve (3), or C B.

$$\therefore \text{E I}\frac{d^2y}{dx^2} = P_1(3a-x) + \frac{p}{2}(4a-x)^2 - V_1(4a-x) \ldots\ldots (a_3)$$

Take the moments about every point in curve (4), or B A.

$$\therefore \text{E I}\frac{d^2y}{dx^2} = \frac{p}{2}(4a-x)^2 - V_1(4a-x) \ldots (a')$$

Integrate (a_1) between the limits: $x = a$ and $x = x$. If $x = a$ (*i. e.* at the point D, which is the centre point of the middle span), the tangent to the neutral axis must be horizontal, because the weights and supports are symmetrically situated with respect to it.

$$\therefore \frac{dy}{dx} = 0 \text{ at D.}$$

$$\therefore \text{E I}\frac{dy}{dx} = P_1\left[3ax - \frac{x^2}{2} - \frac{5a^2x}{2}\right] + P_2\left[ax - \frac{x^2}{2} - \frac{1^2}{2}\right] + p\left[16a^2x - 4ax^2 + \frac{x^3}{3} - \frac{37a^3}{3}\right] - V_1\left[4ax - \frac{x^2}{2} - \frac{7a^2}{2}\right] - V^2\left[2ax - \frac{x^2}{2} - \frac{3a^2}{2}\right] \ldots\ldots (b_1)$$

Integrate (b_1) from $x = 0$ to $x = x$. When $x = 0$, then $y = 0$.

$$\therefore \text{E I}\,y = P_1\left[\frac{3ax^2}{2} - \frac{x^3}{6} - \frac{5a^2x}{2}\right] + P_2\left[\frac{ax^2}{2} - \frac{x^3}{6} - \frac{a^2x}{2}\right] + \frac{p}{2}\left[8a^2x^2 - \frac{4ax^3}{3} + \frac{x^4}{12} - \frac{37a^3x}{3}\right] - V_1\left[2ax^2 - \frac{x^3}{6} - \frac{3a^2x}{2}\right] \ldots (c_1).$$

Take (c_1) at the point D, when $x = a$, and call the deflection under P_2, y_2 *i.e.*, let $x = a$ and $y = y_2$

$$\therefore \text{E I}\,y = -\frac{a^3}{6}\left[7P_1 + P_2 + \frac{67}{4}pa - 10V_1 - 4V_2\right] \ldots\ldots (c_2).$$

Integrate (a_2) from $x = a$ to $x = x$.

When $x = a$, then $\frac{dy}{dx} = 0$.

$$\therefore \text{E I}\frac{dy}{dx} = P_1\left[3ax - \frac{x^2}{2} - \frac{5a^2}{2}\right] + \frac{p}{2}\left[16a^2x - 4ax^2 + \frac{x^3}{3} - \frac{37a^3}{3}\right] - V_1\left[4ax - \frac{x^2}{2} - \frac{7a^2}{2}\right] + V_2\left[2ax - \frac{x^2}{2} - \frac{3a^2}{2}\right] \ldots (b_2).$$

At the point C the tangent to the curve is not horizontal, as is assumed by the experimenter.

$\therefore$ let $\frac{dy}{dx} = t_c$ at C where $x = 2a$, then (b_2) becomes

$$\text{E I}\,t_c = \frac{a^2}{2}\left[3P_1 + \frac{19}{3}pa - 5V_1 - V_2\right] \ldots (b_2)'.$$

Again, integrate (b_2) from $x = 2\,a$ to $x = x$. When $x = 2\,a$, then $y = 0$.

$$\therefore \text{E I } y = \text{P}_1\left[\frac{3\,a\,x^2}{2} - \frac{x^3}{6} - \frac{5\,a^2x}{3} + \frac{a^3}{3}\right]$$
$$+\frac{p}{2}\left[8\,a^2x^2 - \frac{4\,a\,x^3}{3} + \frac{x^4}{12} - \frac{37\,a^3x}{2} + 2\,a^4\right]$$
$$- \text{V}_1\left[2\,a\,x^2 - \frac{x^3}{6} - \frac{7\,a^2x}{2} + \frac{a^3}{3}\right]$$
$$- \text{V}_2\left[a\,x^2 - \frac{x^3}{6} - \frac{3\,a^2x}{2} + \frac{a^3}{3}\right] \ldots\ldots (c_2).$$

Take (c_2) at the point D, thus $x = a$ and $y = y_2$.

$$\therefore \text{E I } y_2 = -\frac{a^3}{6}\left[5\,\text{P}_2 + \frac{43}{4}p\,a - 8\,\text{V}_1 - 2\,\text{V}_2\right] \ldots\ldots (c_2)'.$$

Integrate (a_3) from $x = 2\,a$ to $x = x$. When $x = 2\,a$, then $\frac{dy}{dx} = t_c$

$$\therefore \text{E I}\left[\frac{dy}{dx} - t_c\right] = \text{P}_1\left[3\,a\,x - \frac{x^2}{2} - 4\,a^2\right]$$
$$+\frac{p}{2}\left[16\,a^2x - 4\,a\,x^2 + \frac{x^3}{3} - \frac{56\,a^3}{3}\right]$$
$$- \text{V}_1\left[4\,a\,x - \frac{x^2}{2} - 6\,a^2\right]$$

Add to this $(b_3)'$

$$\therefore \text{E I } \frac{dy}{dx} = \text{P}_1\left[3\,a\,x - \frac{x^2}{2} - \frac{5\,a^2}{2}\right]$$
$$+\frac{p}{2}\left[16\,a^2x - 4\,a\,x^2 + \frac{x^3}{3} - \frac{37\,a^3}{3}\right]$$
$$-\text{V}_1\left[4\,ax - \frac{x^2}{2} - \frac{7\,a^2}{2}\right] - \text{V}_2\,\frac{a^2}{2} \ldots (b_3).$$

Take (b_3) at B when $x = 3\,a$ and let $\frac{dy}{dx} = t_b$

$$\therefore \text{E I } t_b = \frac{a^2}{2}\left[4\,\text{P}_1 + \frac{26}{3}p\,a - 8\,\text{V}_1 - \text{V}_2\right] \ldots\ldots (b_3)'$$

Integrate (b_3) from $x = 2\,a$ to $x = x$. When $x = 2\,a$, then $y = 0$.

$$\therefore \text{E I } y = \text{P}_1\left[\frac{3\,a\,x^2}{2} - \frac{x^3}{6} - \frac{5\,a^2x}{2} + \frac{a^3}{3}\right]$$
$$+\frac{p}{2}\left[8\,a^2x^2 - \frac{4\,a\,x^3}{3} + \frac{x^4}{12} - \frac{37a^3x}{3} + 2\,a^4\right]$$
$$- \text{V}_1\left[2\,a\,x^2 - \frac{x^3}{6} - \frac{7a^2x}{2} + \frac{a^3}{3}\right]$$
$$- \text{V}_2\left[\frac{a^2x}{2} - a^3\right] \ldots\ldots (c_3).$$

Take (c_3) at B when $x = 3\,a$, and $y = y_1$, say,

$$\therefore \text{E I } y_1 = \frac{a^3}{6}\left[11\,\text{P}_1 + \frac{93}{4}pa - 20\,\text{V}_1 - 3\,\text{V}_2\right] \ldots\ldots (c_3)'.$$

Integrate (a_4) from $x = 3\,a$ to $x = x$. When $x = 3\,a$ then $\frac{dy}{dx} = t_b$

$$\therefore \text{E I}\left[\frac{dy}{dx} - t_b\right] = \frac{p}{2}\left[16\,a^2x - 4\,a\,x^2 + \frac{x^3}{3} - 21\,a^3\right] - \text{V}_1\left[4\,a\,x - \frac{x^2}{2} - \frac{15\,a^2}{2}\right]$$

Add to this $(b_3)'$

$$\therefore \text{E I } \frac{dy}{dx} = 2\,\text{P}_1\,a^2 + \frac{p}{2}\left[16\,a^2x - 4ax^2 + \frac{x^3}{3} - \frac{37\,a^3}{3}\right] - \text{V}_1\left[4\,ax - \frac{x^2}{2} - \frac{7\,a^2}{2}\right]$$
$$- \text{V}_2\,\frac{a^2}{2} \ldots\ldots (b_4).$$

Integrate (b_4) from $x = 4\,a$ to $x = x$. When $x = 4\,a$ then $y = 0$.

$$\therefore \text{E I } y = 2\,\text{P}_1\,a^2\left[x - 4a\right] + \frac{p}{2}\left[8a^2x^2 - \frac{4ax^3}{3} + \frac{x^4}{12} - \frac{37\,a^3x}{3} - \frac{44\,a^4}{3}\right]$$
$$- \text{V}_1\left[2\,ax^2 - \frac{x^3}{6} - \frac{7\,a^2x}{2} - \frac{22\,a^3}{3}\right]$$
$$- \text{V}_2\left[\frac{a^2x}{2} - 2\,a^2\right] \ldots\ldots (c_4).$$

Take (c_4) at B when $x = 3\,a$ and $y = y$.

$$\therefore \text{E I } y_1 = -\frac{a^3}{6}\left[12\,\text{P}_1 + \frac{107}{4}p\,a - 26\,\text{V}_1 - 3\,\text{V}_2\right] \ldots\ldots (c_4)'$$

Subtract $(c_1)'$ from $(c_2)'$

$$\therefore 2\,\text{P}_1 + \text{P}_2 + 6\,pa - 2\,\text{V}_1 - 2\,\text{V}_2 = 0 \ldots (d)$$

also subtract $(c_3)'$ from $(c_4)'$

$$\therefore 23\,\text{P}_1 + 50\,p\,a - 46\,\text{V}_1 - 6\,\text{V}_2 = 0 \ldots (e)$$

The experiment was so conducted that $y_2 = y_1$.

Then subtract $(c_4)'$ from $(c_2)'$

$$\therefore 7\,\text{P}_1 + 16\,p\,a - 18\,\text{V}_1 - \text{V}_2 = 0 \ldots (f)$$

From (e) and (f) by elimination

$$62\,\text{V}_1 = 19\,\text{P}_1 + 46\,p\,a \ldots (h)$$

and $62\,\text{V}_2 = 92\,\text{P}_1 + 164\,p\,a \ldots (k)$

Substitute these in (d)

$$\therefore \frac{\text{P}_2}{\text{P}_1} = \frac{49}{31} + \frac{24\,p\,a}{31\,\text{P}_1} \ldots\ldots (g)$$

Let b = breadth of bar,
and d = depth of bar.

Assume that a cubic inch weighs $\frac{5}{18}$ lbs. (*i.e.* 480 lbs. per cubic foot), then

$$p\,a = \frac{5}{18}\,a\,b\,d = \frac{20}{3}\,b\,d, \text{ if } a = 24 \text{ inches.}$$

For the first bar, $p\,a = 3.755$ lbs., $b = 1.535$ inch, and $d = 0.367$ inch.

For the second bar, $p\,a = 2{,}024$ lbs., $b = 0{,}553$ inch, and $d = 549$ inch.

Find the value of the first number of (g), all the quantities in the second number being given.

$$\therefore \frac{\text{P}_2}{\text{P}_1} = \frac{49}{31} + \frac{24 \times 20\,b\,d}{31 \times 3 \times 82.84}.$$

For the first bar this $= 1.581 + 0.035 = 1.617$.

For the second bar this $= 1.581 + 0.019 = 1.6$.

In this experiment $\frac{52.}{82,84} = 1,593$.

This result may be considered to establish the essential correctness of the theory.

Next, a piece 3 feet $11\frac{1}{2}$ inches long was taken from each end of each bar and the central span was covered by the remaining piece from each bar (4 feet $4\frac{3}{4}$ inches long).

If the origin and axes remain as before, and the weight P be applied at D the equation of moments about any point in in D C is

$$E\,I\frac{d^2y}{dx^2} = \frac{p}{2}\left[2a-x\right]^2 - V_2\left[2a-x\right] \ldots (a)$$

Integrate (a) from $x = a$ to $x = x$

When $x = a$ then $\frac{dy}{dx} = 0$

$$\therefore E\,I\frac{dy}{dx} = \frac{p}{2}\left[4a^2x - 2ax^2 + \frac{x^3}{3} - \frac{7a^3}{3}\right] - V_2\left[2ax - \frac{x^2}{2} - \frac{3a^2}{2}\right] \ldots (b)$$

Integrate (b) from $x=2a$ to $x=x$

When $x=2a$ then $y=0$

$$\therefore E\,I\,y = \frac{p}{2}\left[2a^2x^2 - \frac{2ax^3}{3} + \frac{x^4}{12} - \frac{7a^3x}{3} + \frac{2a^4}{3}\right] - V_2\left[ax^2 - \frac{x^3}{6} - \frac{3a^2x}{2} + \frac{a^3}{3}\right] \ldots\ldots (c).$$

Take (c) at D, then $x = a$ and $y = y_2$, say,

$$\therefore E\,I\,y_2 = -\frac{p\,a^4}{8} + V_1\frac{a^3}{3} \ldots\ldots\ldots (c)'$$

But from the principle of the lever

$$V_2 = \tfrac{1}{2}\,P + p\,a$$

$$\therefore E\,I\,y_2 = \frac{a^3}{6}\left[P + \frac{5}{4}\,pa\right] \ldots\ldots\ldots (c)''$$

To obtain $\frac{y_2}{y_2}$ eliminate V_1 or V_2 from $(c_2)'$, $(c_2)'$ or $(c_4)'$ by (h) and (k).

$$\therefore E\,I\,y_2 = \frac{a^3}{186}\left[13\,P_1 + \frac{59}{4}\,pa\right] \ldots\ldots (l)$$

then divide $(c)''$ by (l)

$$\therefore \frac{y_2}{y_2} = \frac{124\,P + 155\,p\,a}{52\,P_1 + 59\,p\,a} \ldots\ldots (m)$$

For the first bar if the weight $P = P_2$ (*i.e.*: 82,84 lbs.), from (m)

$$\frac{y_2}{y_2} = \frac{10272.16 + 582.12}{2704 + 221,68} = 3,71.$$

The value obtained from the experiment was $\frac{y_2}{y_2} = 3,77$.

For the second bar, if $P = P_2$, from (m)

$$\frac{y_2}{y_2} = \frac{10272,16 + 313,72}{2704 + 119,41} = 3,75.$$

The value obtained from the experiment was $\frac{y_2}{y_2} = 4,06$, but as we shall show, the bar was in this case loaded much beyond elastic limits, and the deflection was therefore greater than could be accounted for by elasticity alone, though not differing very widely from that within elastic limits.

For the first bar, if $P = P_1$ in (m),

$$\frac{y_2}{y_2} = \frac{6448 + 582\,12}{2704 + 221,68} = 2,4$$

the result obtained from experiment was

$$\frac{y_2}{y_2} = \frac{1}{0,419} = 2,39.$$

For the second bar, if $P = P_1$ in (m),

$$\frac{y_2}{y_2} = \frac{6448 + 313,72}{2704 + 119,41} = 2,39$$

The value obtained from experiment was $\frac{y_2}{y_2} = \frac{1}{0,391} = 2,57$, but the bar was in this case also loaded somewhat beyond elastic limits, as indeed were both bars in these last four experiments. The first bar seems to have been of better material than the second.

To find the resistance which the bars oppose to rupture or to flexure, use the formula proved by Weisbach and other writers on the resistance of materials for a rectangular beam (of span $= 2a$), loaded with a weight P and with the uniform load $2\,p\,a$

$$\therefore P = \frac{b\,d^2}{3\,a}\,T - p\,a \ldots\ldots (n)$$

According to Weisbach when $T = 17000$ lbs., (n) gives the value of P which will strain a wrought iron beam to the limit of elasticity.

For the first bar, from (n), $P = 49.5 - 3.75 = 45.75$ lbs. which is the weight that placed at the centre of a four foot span will strain the bar to the limit of elasticity, but there are indications that this first bar was of unusual elasticity, which are derived from the observed valves of y_2 and y_2. So that it no doubt afforded a much greater resistance than the above before passing elastic limits. Similarly for the second bar, from (n) $P = 39.36 - 2.02 = 37.34$ lbs. There

are no indications in the observed deflections of the second bar that it was of extra quality, but the contrary.

It will then be perceived how truly it was overloaded by a weight of 82.84 lbs. at its centre, and that even 52 lbs. was sufficient to cause an observable deviation from elastic flexure, which entirely accounts for the discrepancies between the ratios derived from computation and experiment.

STUDIES RELATIVE TO THE IMPROVEMENTS WHEREOF THE CONSTRUCTION OF METAL-WAYS IS SUSCEPTIBLE.

By M. D. Soignie, Engineer, Brussels.

Journal of the "Iron and Steel Institute."

Among the causes which are opposed to the beneficial development of the construction of railways there are two, which are the principal that are indirectly connected with the great industry of the manufacture of iron and steel—that is to say, first, the considerable expense which the working of railways cause for maintenance; second, the too heavy cost of the first establishment of the permanent way properly so called.

These studies have for their object the discovery of a means of sensibly lessening these expenses in order to permit companies to work advantageously lines established in localities but little favored, and to thus rapidly increase the sum of the moral and physical well-being which these railways are destined to produce. Our attention has notably been drawn to the increase of the resisting quality of the iron rail; to the extension of the duration of its supports; and to the means of arriving at the passage of heavy gradients with locomotives of relatively light weight.

In order to attain these ends, we have imagined:—1st. A process of lamination calculated to improve the quality of the T rails. 2d. A new form of rails sensibly increasing their durability, other things being equal. 3d. A system of making rails with an entire super-raised face. 4th. A system of entire metallic way applicable to lines of large traffic, tramways, and lines in the interior of mines. 5th. A system of fastening with bolts with elastic pressure. 6th. A rail with an arched rolling crown increasing the adherence (bite) of the locomotive.

We will briefly describe these systems. Experience demonstrates that the resistance of iron rails is no longer sufficient to bear, during a lengthened period, the enormous traffic which is at present developed upon railways; that this deterioration has become so rapid, is ascribable, in our opinion, to two causes. To the decrease in the quality of the iron used in the manufacture of the rails, on the one hand; to the great weight per locomotive axle which their construction entails, on the other hand. The decrease in the quality of the iron of the rails arises from the use in the blast furnaces of an excessive proportion of silicious ores, of slags, which affords a ringing iron, but an iron breaking without tenacity; this decrease is again induced by the tendency of the manufacturers to finish their rails at too high a temperature. The impoverishment of the strong iron ores, the vignole shape given to the rails, compel the makers to act to a certain extent in this manner. Our system of lamination has for its object the avoidance, within the limits of possibility, of this state of things. In order to correct the deficiency of tenacity in the flanges of the rails, the dominant cause which augments their deterioration, we remedy thus:—1st. By a much more energetic compression of the iron forming the T rail. 2d. By a welding at a less temperature at the finishing rolls, without fearing the rending of the flange of the rail. In order to attain these results, the rail prepared by the ordinary method up to a certain point is completed in our special rolling mill, which is composed of three finishing rolls of a dimension of 0.70 m. at least, traveling at the rate of 1 m. per second, at the most, of which two are horizontal and the third vertical, cast in a mould intended to compress, temper, and polish highly the crown of the rail. As the finishing rolls are usually arranged, the swelling of the flange of the rail is obtained by the flattening or compressing of

the iron in the finishing grooves. This effect is evidently very prejudicial to the tenacity of the iron, inasmuch as instead of compressing the molecules, they are dilated exactly at the spot where the wheels most sensibly infringe on the rails.

By our arrangement, instead of dilating the iron, we strongly compress it, absolutely as would be done by the forge-hammer acting upon the crown of the rail, and with so much the greater efficacy, as the process of the welding is slow, and the diameter of the rolls large. On the other hand, it is well known that the more granulated iron is laminated at a low temperature the closer the pores become attached, which renders it more pliant and more hard. The contrary effect takes place when the same iron is finished hot, and that is what is effected with the mills of three rolls that are used in the present day. We avoid, moreover, this inconvenience without apparatus. The slow lamination, added to the continuous watering of the vertical compression cylinder, draws out the flange of the rail at a relatively low temperature, at the same time giving to it a sort of tempering which considerably augments the hardness and tenacity of the iron. This retardation in the definite lamination will not, moreover, produce rending in the flange of the rails; it is known that that never takes place in the last groove.

2d. Rail with crown super-raised.

Experience demonstrates that the deterioration of the T rail is so much the more prompt, the more decided the flattening of the head of the rail is in consequence of the wear and tear (friction). In fact, it must be so, inasmuch as the bearing of the tires of the wheels then act upon the edges, which are always the most feeble points of the rails; the tangential efforts of the wheels thus augmenting by the breadth of contact, this course of destruction becomes added to the former.

The action of the flange of the wheel tire upon the edges of the rails is also very detrimental, particularly at the curves, because the weight thus becomes localized upon a very small surface, where the iron offers the least guarantee of resistance. The form recommended, if given to the T rail, obviates entirely these inconveniences. The form under notice retains the breadth of the upper zone of the rail, whatever may be the wear and tear, within suitable limits, and the weight can no longer act upon the edges of the rails, but only towards the centre where they have a considerable resistance, and where the quality of the iron is always superior. It is known by mechanical action of cylinders that the iron is always less sound towards the salient points than towards the centre of a section.

Experiments, carried on for the last two and a-half years, corroborate completely our provisions. They prove by evidence that the duration of these rails is more than tripled; and even rails of the description laid down since the 30th of May, 1871, upon a gradient of twenty-five millimetres, where, according to an official report, the rails of the usual form did not last three months, are still in good condition, although very heavily used, that is to say, that up to the present time their duration is nine times greater than the rails of iron that were previously laid down upon the same place. These facts require no commentaries, and will make it comprehensible, we hope, that the interests of masters of Ironworks and Railway Companies is closely linked with the adoption of this practical form very suitable to bring up again the use of iron rails.

3d. Method of manufacturing the rail with a super-raised crown of steel.

The super-raised crown of rails of the form whereof we have just made mention, being of steel, it can be easily comprehended that the duration of such rails will bear comparison with those of the best rails made entirely of Bessemer steel. This form permitting moreover the trimming in the portion of steel in the interior of the mass, it will be much easier to weld this portion in iron and to be thus able to obtain mixed rails at a moderate figure, capable of resisting the most destructive traffic.

4th. System of line entirely metallic.

The substitution of iron for wood, as the support of the rails, interests as well ironmasters as the workers of railways. Our system, sanctioned by experiments that have been carried on for nearly three years, has this remarkable characteristic, that similar lines can be established in ordinary times at a less price for the first laying down thereof than the vignole line

upon wooden sleepers. Enormous savings in maintenance evidently emanate from this appliance.

This metallic line laid down, and permanent, is constructed of rail supports of iron; that is to say, vignole rails carrying invariably their supports, easily transported in that state, connected together by tie pieces. If a rail becomes defective it can be raised together with its supports, and is replaced by another rail and support. The support of the first rail can be used again. These rail supports of a new sort are upon a different principle to those upon which the English Barlow rails and the German Hartwich rails rest, without having the incoveniences of these latter. As the iron supports possess a duration almost indefinite, it is provable that after 36 years working, the kilometric saving realizable is more than 174,000f. The same system slightly modified applied for tramways afford savings even still more considerable. For the railways in the interior of mines it also offers great advantages, and our system of tie piece may there supersede the use of wooden sleepers. It is evident what fresh and important outlets the iron-works may find by the application of this means, the first expense no longer being an obstacle to the use of iron as the support of rails.

5th. System of splicing with bolts and elastic fastenings. The screws of the fish bolts, such as are used in the present day, under the influence of the tremulation caused by the passing of trains, soon become loosened, and consequently the splicing fails in its intent. It happens also that the violent shocks sustained by the nuts break the worms of the screws, and render the bolts unserviceable. The rusting of the threads of the screws is also a case of waste. Our system obviates these inconveniences by means of simple appendages to be placed below the flat of each screw. The appendages are composed of a washer of India-rubber encircled by a ring of iron upon which the flat rests after being fastened. By this means, as experience proves, the shocks are deadened, and the threads of the screws thoroughly preserved. The junction of the rails is, therefore, much more perfect, the roll of the carriages more gentle for travelers, and the preservation of the material stationary. The Belgian Government has resolved to apply this system of splicing, which does not cost more than about 60 cents per pair of splints. This system does not entail any alteration in the form of the bolts, nor in the splinting plates. It is consequently very easy for companies working lines to apply the same.

6th. Rails with crowns striated.

It is known that the adherence (bite) of the locomotives corresponds to a fraction of the total weight divided between the coupled wheels. It is proved also that this friction increases in an inverse ratio to the surfaces in contact with the wheels. It is this latter property that we utilize to prevent the sliding of the wheels upon heavy gradients, by supposing the useful adherent weight of the engine inferior to the correspounding power of the locomotive. For this purpose, we make upon the crown of the steel rail, grooves inclined 25 degs. upon the arch sufficiently close, in order that there be no solution of continuity in the rolling. It is perceptible that in this way the pressure of the tires per square centimetre is nearly doubled, and that the sliding of the wheels equally weighted ought to be effected with much greater difficulty. We have not, up to the present time, been able to determine this coefficient, having experimented upon lines striated perpendicularly to the axis, but it is certain that the bite is considerably increased. Although the sliding of the wheels upon these rails takes place less rapidly, we do not think that the resistance to the rolling will sensibly be increased, since the frictions of the sliding, or of rolling, are quite different. If the ulterior experiments are conclusive, these striated rails which would be laid down solely upon heavy gradients, would effect a complete transformation in the construction of the locomotives, and even in the railways, because the weight and axle might be reduced. The rails and the supports would consequently suffer much less. To ascend very great gradients upon a railway with stiff curves would no longer be a problem almost unsolvable. We draw the attention of engineers to this innovation.

Steel Rails on the Paris, Lyons and Mediterranean.—It appears that steel rails have now been laid down over 207½ miles of this system. Of the section thus steel-railed, 160 miles are comprised in the main line between Paris and Marseilles, in which, of course, the heaviest and most important traffic occurs.

ON PHOSPHORIC BRONZE AND ITS PRINCIPAL INDUSTRIAL USES.

By M. C. Montefiore Levi, Val Benoit, Liege.

Journal of "The Iron and Steel Institute."

Although the subject of the present note might be considered as not strictly within the limits of the subjects to be submitted to the discussion of the Iron and Steel Institute, it nevertheless bears such an intimate relation to the methods of manufacture of iron and steel, that we do not hesitate to bring it under the attention of the Institute.

Our intention is not to establish any comparison between phosphoric bronze on the one hand, and iron and steel on the other, although such a comparison might present a certain interest, but if we take into consideration the importance of being able to produce by casting, that is to say, independently of any complication of shape, a metal possessing the qualities of hardness, absolute resistance, and elasticity in a higher degree than iron, and almost equal in certain cases to steel, together with the faculty of varying at will, and within very wide limits, any or all of these qualities; when, moreover, the metal may be considered as practically inoxidizable, when it shows but a slight friction against iron or steel, when it does not vary in structure by shocks or concussions, however often repeated, and preserves the entire intrinsic value of the metal when worn out or otherwise out of use, it will be admitted that the study of the qualities of such an alloy is of considerable interest to all who construct or use the numerous tools and powerful engines required for the production of iron in its many varieties.

The attention of the readers of English and foreign reviews and scientific journals has been on more than one occasion drawn to phosphoric bronze. We may specially mention the *Engineer* of the 8th July, 1870, and the 23d February, 1872, and *Engineering* of the 9th September, 1871, and the 4th October, 1872. These articles refer more particularly to the origin and to the first trials and industrial appliances of phosphoric bronze.

Prolonged experience in the manufacture has produced a more perfect knowledge of the properties and preparation of the alloy; it is thus that a far superior degree of resistance and of elasticity has been attained, while it has now become easy to give either of these qualities the desired predominance together with more or less hardness according to the special purpose to which the metal is to be applied.

The following table shows the result of five trials of tensile strength, made by Mr. Kirkaldy upon bars composed of one identical alloy, submitted to different processes of manufacture:—

Nos.	Ultimate Stress per Square In. Lbs.	Elastic Stress per Square In. Lbs	Ultimate Permanent Extension. Per Cent.
1.	74·966	55 800	2·35
2.	73·987	55·200	3·20
3.	63·653	40·500	9·40
4.	54·060	26 300	31·30
5.	50·120	21·700	39·10

The Ministry of Public Works for Germany, struck by the remarkable qualities of the alloy, ordered, as a work of public utility, a series of trials to be made at the expense of the Government. As these trials, similar in nature to those made constantly during the last eight years upon the iron and steel employed in the manufacture of rolling stock and railway plant, are of considerable importance, we will in a few words describe the means used and the end attained.

The trials at Berlin have proved the correctness of the hypothesis so often broached, that iron and steel, if submitted to continually repeated efforts of tension, torsion, or flexion, give way, probably in consequence of a molecular modification of structure under an effort often considerably below that of their absolute resistance under one single strain.

These trials were undertaken by the Prussian Government with the object of establishing as a fact, that the absolute resistance and elasticity of a metal being known, such metal can only with perfect security be submitted to a limited given number of strains of a given strength in all cases inferior to the limit of its absolute resistance. M. Reuleaux, Conseiller intime, and M. Spankenberg, engineer, are conducting these trials with phosphoric bronze. Highly interesting and elaborate details of the methods and apparatus employed by them may be found in the work of M. A. Wöhler, entitled

"Ueber die Festigkeitsversuche mit Eisen und Stahl. Berlin, 1870. Ernst ü Korn."

The first series of these experiments with phosphoric bronze as compared with ordinary bronze or gun-metal, were begun in April and ended towards the middle of May of the present year, with the following results:—A bar of phosphoric bronze was submitted successfully to 408,230 tractions, with an effort of 200 cwt. per square inch, while a first bar of ordinary bronze broke at an effort below 200 cwt. and a second bar resisted only 4,200 tractions. A second bar of phosphoric bronze has, at the present time, resisted 147,840 tractions with an effort of 250 cwt. per square inch, and this experiment is still in progress.

In a trial for flexion, with a maximum strain of 200 cwt. on the external fibres of the bar, these fibres alone were broken through after 862,980 flexions, while a similar bar of ordinary bronze, under the same strain, was broken completely through after 102,650 such flexions. A second bar of phosphoric bronze, under an effort of 180 cwt. per square inch, has, up to this date, borne 1,260,000 flexions without as yet showing any signs of deformation or of rupture.

We now come to a series of industrial appliances. A peculiar composition of phosphoric bronze, destined specially to resist friction, has been in use for several years on a large scale for bearings, particularly for rolling stock, and, among others, the Grand Central Railway Company, of Belgium, employed these bearings exclusively for all its cars and carriages. Many works, both in Belgium and Germany employ this alloy for engine and machinery bearings. The trials made have shown that the wear by friction is about five times less than that of ordinary bearing brasses, while the axles remain unaltered. Several ironworks, among which we may mention Messrs. Gillieaux and Co., at Charleroi Blondiaux and Co., at Thyle-Chateau, Thorneycroft, at Wolverhampton, and De Wendel and Co., at Hayange, make constant use of large toothed wheels, in phosphoric bronze, for the gearing of their rolling mills in all cases where the shocks are severe. Experience has shown that in no case has a tooth of such a wheel been broken, and that the wear is less than half that of ordinary bronze. (See, for further particulars concerning this special appliance, and also on the use of phosphoric bronze for transmission shafts for rolling mills, a note published in the "Bulletin du Museé, de l'Industrie of Belgium.")

In the February number of *Engineering*, for 1873, an article was published on the use of phosphoric bronze for tuyeres, showing that such tuyeres are much superior to those in ordinary bronze, and that after a year's service they show neither fissure nor incrustations of slag or cinder. These tuyeres, already largely used in Germany, are now being tried both in England and in France.

The great resistance of phosphoric bronze has led to its use for the manufacture of cylinders both for steam fire-engines and for hydraulic presses. Messrs. Merryweather have applied it to the first of these purposes, as may be seen in all the fire-engines sent by them to the Exhibition at Vienna. Messrs. McKean and Co. have also employed it in the construction of the apparatus they have made for the boring of the St. Gothard tunnel. The great elasticity of phosphoric bronze, and its easy friction on iron, have been very successfully taken advantage of in the construction of packing rings for steam pistons.

Phosphoric bronze may be drawn out into wire, and by this process it acquires a resistance at least equal to that of any other metal capable of being drawn into wire. The following table gives the results of trials made at Mr. Kirkaldy's of such wire:—

Metals.	Pulling Stress per sq. inch.		No. of Twists in 5 inches of Wire.		Ultimate extension in per cent.
	As drawn	Anml'd.	As drawn	Anml'd.	
	lbs.	lbs.	lbs.	lbs.	
Phosphoric Bronze	102·750	49·851	6·7	87·0	37·5
Do.	120·957	47·787	22·3	52·0	34·1
Do.	120·950	53·381	13·0	124·0	42·4
Do.	139·141	54·153	17·3	53·0	44·9
Do.	159·915	58·853	13·3	66 0	46·6
Do.	151·119	64·569	15 8	60 0	42·8
Copper	63·122	37·002	86·7	96 0	34·1
Steel	120·976	74 637	22·4	79·0	10·9
Best Charcoal Iron	65·834	46.160	48 0	87·0	28 0

Besides its high absolute and elastic resistance, phosphoric bronze possesses in common with all alloys, where copper predominates, the advantage of not becoming crystalline, as is the case with steel and iron, under repeated concussions. It is, therefore, well adapted for the

manufacture of mining and other ropes. The prime cost is higher than the ordinary material, but it is probable that the cost in the long run will be less, as while resisting atmospheric and corrosive influences, it preserves, when worn out, its intrinsic value.

Phosphoric bronze of a suitable composition can be perfectly rolled and hammered. In Russia, several millions of cartridges have been made of this metal, and have been shown to bear firing as often as 120 times in succession, without being torn or otherwise injured.

As sheathing, it resists the action of sea water much better than copper. The following table gives the comparative result of six months action of sea water on rolled phosphoric bronze on the one hand and of yellow sheathing metal on the other, the surfaces acted upon being equal in size.

Metal.	Weight before Immersions.	Weight after Immersions.	Loss.	
			Kilogs.	Per cent.
	Kilogs.	Kilogs.		
Sheathing Metal	33·825	32·805	1·020	3·015
Do.	40·413	39·160	1·253	3·100
Phosphoric Bronze....	31·615	31·260	0·355	1·123
Do.	51·970	51·350	0·620	1·193

A similar trial, made for the purpose of ascertaining the difference of resistance to the action of an acid solution between rolled phosphoric bronze and copper, showed for three months action of sulphuric acid marking 10 degs. Baume, at the atmospheric temperature, a loss of 4.15 per cent. in the copper, and of only 2.3 per cent. in the phosphoric bronze.

Trials have been made by several Governments in regard to the use of phosphoric bronze for artillery purposes. In every one of these trials, the resistance (toughness) of the alloy has proved superior to that of ordinary gun metal, and it is only at this point of view, which alone interests its industrial appliances, that we refer to these trials in the present paper. In Belgium, at comparative trials made with bursting charges, the ordinary bronze gun burst explosively at the second round with 1,250 grms. of powder, and a projectile of 8,518 grms., while the phosphoric bronze gun resists this charge perfectly, the normal charge being 500 grms. of powder and a shot of 3,000 grms. In France, at the comparative trials with bursting charges, the ordinary bronze gun burst explosively at the second round with 1,500 grms. of powder, and a projectile of 16,000 grms., while the phosphoric bronze gun, after firing five rounds with a similar charge, burst only at the second round, with a charge of 1,750 grms. of powder and a projectile of 20,000 grms.: the cylinder had, however, got jammed into the gun. The normal charge was 550 grms. of powder and a shot of 4,000 grms. In Prussia, the comparative trials were made by firing constantly normal charges, and turning off a certain thickness of metal in the chamber after each fifty rounds. It was found that the dimensions of the phosphoric bronze guns were only altered by the firing, when the thickness of the metal had been brought down below that adopted for steel guns of the same calibre.

The Belgian Government has accepted the phosphoric bronze for the manufacture of the box of the Comblain Rifles, and for the harness buckles of the cavalry.

At the present time, besides the works at the Valbenoit, near Liege, three companies are in existence for the manufacture of phosphoric bronze, namely, Messrs. G. Höper and Co., at Iserlohn, in Germany; the phosphoric Bronze Company, at Pittsburg, in the United States; and the Phosphoric Bronze company, Limited, 110, Cannon Street, London, in England. The latter has exhibited several of the appliances of this metal at the Kensington Exhibition.

THE DELTA OF THE DANUBE.

By Sir Charles Augustus Hartley.

From Proceedings of the Institute of Civil Engineers.

The Danube, after a course of 1,700 miles, during which it receives more than four hundred tributaries, and drains upward of 300,000 square miles of country, passes the Bulgarian town of Isaktcha—the inland limit of the Commissioner's jurisdiction—in a single channel 1,700 feet in breadth and 50 feet in depth. Isaktcha is situated

on the right bank, at a distance of 40 English miles below the large corn-exporting port of Galatz. Isaktcha is 76 miles from the sea, following the course of the Kilia branch of the Danube; 78 miles by the Sulian branch; 90 miles by the St. George branch; and 58 miles from the sea in a straight line.

At 15 miles below Isaktcha the head of the delta is reached, at a spot called Ismaïl "chatal" or fork, and it is here that the fresh waters divide never again to reunite; as seventeen twenty-seventh of their volume pass onward in an easterly direction by the Kilia branch, and the remaining ten twenty-sevenths take a south-easterly direction by the Toulcha branch.

The Kilia maintains a wide and deep channel for 12 miles N. E. of the chatal to the town of Ismaïl, whence a communication by water exists with Lake Yalpuc, at the upper end of which is the frontier town of Bolgrad. Ismaïl occupies a fine situation on the left bank, but is of slight commercial importance. Its once famous fort was totally destroyed, soon after the conclusion of the Crimean war. From Ismaïl the Kilia trends, for about eight miles, in a S. E. direction, to a bend which directs the waters again to the N. E. Soon afterwards the river is divided into three branches, all of which maintain a navigable depth.

These meet together again at Staroi-Kilia, at about two miles below the town of Kilia, and 44 miles from the chatal. Down to this point the greater portion of the left bank of the Kilia forms the southern boundary of the great Russian Steppe, and is raised far above the level of inundation.

It is only here that it assumes the character of the opposite bank, which is liable to be flooded, throughout its entire length, during times of extraordinary high water. At 5 miles below Staroi-Kilia, the river again separates into three branches, which, after a course of 12 miles, once more unite and flow in a single channel, for four miles further, to the large basin of Vilkovi, situated at four miles from the N. E. angle of the delta.

Between this basin and the chatal, the course of the Kilia, although often separated by numerous islands, continues to pursue, in all its different channels, between well-fixed banks, a sufficient navigable depth for ships of the largest burden.

Below this point, however, these advantages are lost, for the Vilkovi basin is the root of a branch called the Stambul, which withdraws to the S. E., through swampy ground, half the volume of the Kilia; of the Ochakof, which bears to the N. E., one fourth its volume; and of three other branches, one to the left of the Ochakof and the other two to the right, which absorb the remainder.

These five branches, moreover, afterwards split into smaller channels, so that finally the waters of the Kilia are delivered to the sea by at least twelve distinct mouths, not one of which is navigable, except for fishing vessels.

At 11 miles below Ismaïl chatal, the Toulcha branch separates into two channels, the St. George and the Sulina. This point is called the St. George chatal.

The course of the St. George is generally in a S. E. direction; it bears with it four-fifths of the waters of the Toulcha branch, or eight twenty-sevenths of the volume of the main river at Isaktcha; its average width is 1,200 feet, and at seasons of extreme low water the depth of its navigable channel is nowhere less than 16 feet.

At two miles from its chatal, the St. George commences to skirt the foot of the Besh-Tepeh hills, with which it continues parallel for about 10 miles. It then quits its hitherto nearly straight course, and commences the first of a series of windings, for which its central and lower portions are remarkable. From the ample and uniform depth and width of the river, however, these windings are not such obstacles to the navigation as might be supposed. At 29 miles from the St. George chatal, a small stream called the Donavitza, branches off from the right bank, and, after a long and tortuous course, communicates with the vast shallows of the salt-water lake of Raselm. This lake is connected with the Black Sea, by a small channel called the Portiza, the mouth of which is barely navigable for small boats. Owing to this separate outlet to the sea, the Donavitza has been termed, by some writers, a branch of the Danube, but its insignificant section, of less than 50 square yards, by no means entitles it to such an appellation. At the small hamlet of Galinovak, 42 miles from the chatal, such a very sharp bend in the river is encountered that a cutting of only 1,700 feet in length, through the narrow neck of land separating its two parallel reaches, would shorten the course of the river full three miles.

Hence the river continues, with a broad and deep and less tortuous course, to the upper Olinka Island, where it separates into the branches of Kedrilles and Olinka, the former of which delivers almost immediately into the sea, in an E. direction, by a channel across the bar varying in depth from 5½ feet to 8½ feet, two-thirds of the volume of the St. George; while the Olinka channel carries off the remaining third, which is soon spread over the shallows that extend for some miles to the south of the Olinka Islands.

The general direction of the course of the Sulina is to the east. It abstracts one-fifth of the waters of the Toulcha branch, or two twenty-sevenths of the volume of the main river, and its navigable width is rarely more than 300 feet. Between the St. George chatal and the port of Sulina, there are nine shoals, the depth over which, during the seasons of low water, varies from 10 feet to 14 feet; although throughout the spring and early summer, when the waters are high, there is a depth of at least 16 feet over a width of 300 feet.

The entrance to the Sulina branch is of difficult navigation, owing to the acute angle which it makes with the Toulcha, and also by the sand-banks which are formed by the counteraction of the current, which, in entering the Sulina, is opposed in direction to the parent stream.

These obstacles, combined with the many intricate windings, and the numerous shallows which occur in the upper portion of this branch, render the navigation of the Sulina at all times hazardous and difficult. It is not until the extraordinary sinuosity known by the name of the letter M has been passed, and the last shoal, situated at 30 miles below the St. George chatal, has been avoided, that the anxious mariner feels secure for a safe course for the remainder of his downward voyage.

For the last 22 miles, the Sulina maintains a good, navigable passage to the sea, which is reached at 52 miles from the St. George chatal, or at 63 miles from the chatal of Ismail.

The Delta proper of the Danube may be briefly described as being bounded on the north by the Kilia branch, on the south by the Toulcha and the St. George branches, and on the east by the Black Sea. The enclosed space, which comprises an area of 1,000 sq. miles, is a triangular piece of land of which the Ismail chatal is the western apex, and the sea-coast extending from the mouths of the St. George to those of the Kilia, the base.

The Delta, with the exception of a few patches of cultivation on the borders of the St. George and Kilia branches, is entirely destitute of culture. Reeds of large growth cover the greater portion of its surface, and large swamps and fresh-water lakes are met with in every direction. On each of the islands of St. George and Leti, to the north and south of the Sulina, there is a large natural forest of oaks, many of which are three feet in diameter, and belts of willow trees clothe the convex shore of the St. George at every bend of its course.

The population of the Delta does not exceed 6,000 souls, and is chiefly composed of Greeks and Russians, although, since the Crimean war, all the islands below Isaktcha have been in the possession of Turkey.

The soil of these islands is composed of finely-comminuted alluvians, and is entirely free from stones, gravel, or even coarse grained sand. During extraordinary high floods, the Delta, being unprovided with artificial banks, to contain the swollen waters, is almost entirely submerged, while at seasons of drouth its banks are elevated from 10 to 12 feet above the level of the river, at the Ismail chatal, and from 8 to 10 feet at the chatal of St. George. In the lower reaches of each of the three branches, the level of the river is but little affected by the variations of the upland water.

Adjacent to its mouths, it never varies more than one foot, except when influenced by the wind.

During high floods, the inclination of the surface water of the Sulina branch is three inches per mile, but during extreme low water it does not exceed ½ of an inch per mile. Along the seaboard, the shore is rarely more than two feet above the main sea level; near the St. George mouth, however there is a long stretch of sandhills from eight to ten feet in height, and adjoining the Stambul mouth of the Kilia are to be found dunes having an altitude of from 40 to 50 feet.

During ordinary high water, when the current has attained a velocity of from 2½ to three miles an hour, the Danube, before it divides at Ismail chatal, delivers a volume of water equal to 19½ millions of cubic feet

per minute, while during the dry season, when the current has been reduced to one mile an hour, the flow does not exceed 7½ millions cubic feet per minute. At times of extraordinary floods, such as occurred in March, 1861, the velocity is increased to five miles per hour, and the volume of water then delivered by the Danube to the sea was equal to 60 millions of cubic feet per minute, or eight times the quantity discharged at ordinary low water.

Great care has been taken to ascertain the comparative amount of deposit held in suspension during ordinary summer floods, and when the river has fallen to its lowest water level. These results will probably be published in detail hereafter. At present it is sufficient to state, that when the waters are most surcharged, they bear to the sea as much sedimentary as would be equivalent to a deposit of one inch to one cubic foot of water; and, that not more than one-fortieth part of this proportion is transported when the floods have subsided.

Thus, at the former period, upwards of 600,000 cubic yards of diluvial detritus pass into the sea, by the several mouths of the river, in twenty-four hours, and at the later period not more than 15,000 cubic yards.

The results of these investigations account, in a great degree, for the changes which take place, from to time, in the position and extent of the sand-banks forming the bars across the several mouths of the river. At times of high flood, these bars are further from the shore, their magnitude is increased, and the depths over them are diminished.

Thus the effect of a flood current, surcharged with earthy matter is, first of all by its quickened speed to deepen the channel over the bar. The displaced portion is pushed out into the shallows beyond, and there the river waters, checked by the nearly stationary waters of the sea, precipitate the heavier particles of the matter held in suspension to form a new bar; while the lighter particles are carried further, and widely distributed over the sea depths beyond.

The accuracy of this theory is further supported by the fact, which is well known to all the most experienced pilots on the river, that, during times of inundation from the upland waters, the bars are not only shallower, and further removed from the shore, but they are incrusted with hard sand which yields with the greatest difficulty to the plowing action of a vessel's keel.

This stratum of sand is undoubtedly of river origin, and evidently owes its freedom from impurity to the shifting and cleansing process exercised upon it by the waves during stormy weather.

The distance, and the height, at which the new bar is formed, are of course much influenced by the direction of the winds that happen to prevail at the time of the floods.

As soon as the floods subside the effect produced by the strong current ceases, the new formations are gradually pared down by the action of the ground waves; the alluvium of the river is precipitated nearer the shore, and the bars by degrees resume their old position with regard to the shore line; which they retain till the advent of another flood causes the same process to be repeated. The deposits which form the bars, although stretching across the mouths in every case, extend only a short distance to the north, but to a very considerable distance to the south.

This effect is produced by the combined influence of the northerly winds and of the littorol current, which latter, during these winds, and in calm weather, constantly flows towards the Bosphorus.

There are no tides in the Black Sea, and the level of the water along the coast of the delta is solely influenced by the opposing action of the land and sea winds.

Thus, when the westerly wind blows violently, the sea falls 18 inches below its mean level, and when strong easterly winds prevail, it rises 2 feet above the same point.

The northeast winds are the strongest, and blowing over comparatively shallow water, produce the most dangerous seas. The largest waves are, however, those produced by the southeast gales, which cross a reach of 500 miles.

The sea depths, opposite the delta, decrease to the north; thus opposite the St. George mouth, at 3 miles from the land, the sounding line gives 16 fathoms, whereas, at the same distance from the Sulina and Kilia mouths it gives but 10 fathoms. The sea slope, immediately in front of the Kilia delta coast line, is still more gradual, although, from the actual base of the Kilia, the bottom rapidly shelves off into deep water.

The distance, however, of the bars from

the shore, the rapid advance of the shelf seawards, and the large volume of water delivered to the sea, all tend to place the mouths of the Kilia in the worst possible condition for successful treatment.

The author instituted a careful comparison of the two accurate surveys, one by the Russian Government in 1830, and the other by the English Government in 1856, from which, it appeared, that during the interval, the shallows at its entrance, advanced fully one mile in, in the direction of the Sulina mouth. This startling extension, in so short a period, the uncertain and changeable nature of the many branches issuing from the Vilkovi, and the distance of the bars from the shore, were the chief considerations which caused the author to form an unfavorable opinion of the Kilia, in spite of its possessing the best river channel. He therefore recommended, in preference, the improvement either of the St. George, or of the Sulina, when the sea depths are greater, and the advance of the sand banks much less remarkable.

In comparing the merits of the latter branches, the author arrived at the conclusion, that, nearly in every respect, the St. George offered decided advantage over the Sulina. After the short description which has been given of these respective channels, it need not be said that the river portions offer no real obstacles, while at every turn of the upper reaches of the Sulina, disaster of every kind is imminent.

It is true that to reach the Kedrilles bar of the St. George, double the length of works would be necessary, and that, consequently the additional expense would be in the same proportion; but it is no less true, that if the sand banks were once passed by such works, the greater sea-depths opposite the St. George would insure, for a much longer period, a constant navigable depth at the sea entrance.

The St. George is not only situated at the salient angle of the Delta, but it is the easiest to reach, and is nearer by 18 miles to the Bosphorus than the Sulina.

It is also most favorably situated with regard to the safe manœuvering of vessels, during N. N. E. winds; as the tread of the coast toward the Portiza mouth gives more sea room, and enables vessels, if caught in a northerly gale outside, to run for shelter under the lee of the S. W. shore of the Delta.

When the author presented his first projects, the commission had before it three other designs, by three eminent technical authorities who had visited the ground, each of whom advocated the adoption of a different branch.

The authors of these several reports differed widely in their estimates of the merits of the three principal branches, and of the difficulties to be overcome, in rendering them navigable for larger vessels.

In one respect alone all were agreed, and that was, in recommending that, in whichever mouth were chosen, the system of improvement should be that of guiding the river waters across the bar, by means of piers projected from the most advanced dry angles of the river's mouth; or, in other words, that of concentrating the strength of the river current by an artificial prolongation of the river banks into deep water.

In the midst of so many conflicting arguments, the English, French, Prussian, and Sardinian Governments referred the whole question to the decision of two military and two civil engineers, the former delegated by England and Sardinia, and the latter by France and Prussia. But this measure, instead of leading to a satisfactory solution, only complicated matters still more; for these gentlemen prepared a very able and elaborate report, in which they recommended the choice of the St. George branch with a sea entry and gates independent of the mouth; a project diametrically opposed in principle to the system of improvement, previously proposed by all the naval and engineering authorities who had visited the several mouths of the Delta and had studied their peculiarities on the spot.

In the mean time, the merchants of Galatz and Ibraila called loudly for some immediate improvement of the Sulina, and urged that the heavy iron rake which, it was alleged, had formerly been so usefully employed by the Turks in deepening the Sulina Bar, should be again applied for the same purpose.

In order to satisfy these demands, and ascertain the value of a means so simple, and so comparatively inexpensive, the commission not only caused the old Turkish rake to be dragged across the bar fifty times a day by a steamer, during three of the finest months of the year, but they also employed during the same time, a steam dredger, capable of lifting 1,000 tons per day, to turn over the bottom of the bar, with a view to enable the river current to

transport the disturbed material into deep water. Now precisely because this current was too feeble, and did not possess the transporting force required, these measures failed to produce any appreciable beneficial effect; and the commission, therefore, after having given the system a fair trial, abandoned it entirely.

The author considering, that, from motives of expediency, it might be deemed desirable to select the Sulina branch definitively, in preference to the St. George branch, had previously prepared an alternative design for permanent works at the mouth of the Sulina; and the Commission, on relinquishing the operations above described, resolved to improve the channel across the bar of that branch by means of guiding piers of a temporary character, but carried out on the lines which the author had designed for the permanent works. The commission arrived at this decision with the view of giving the speediest relief in the cheapest manner. But it was guaranteed that this provisional expedient should not prejudice the choice of the mouth, to be eventually selected for the permanent treatment.

The original design for the permanent works may be thus briefly described. The piers were projected to cross the bar, and terminate in a depth of 18 feet, in order that the proposed channel might be deepened by the concentrated action of the river current and that a good navigable channel should be maintained beyond the piers; it being assumed, that when the troubled waters of the river were brought into immediate contact with the littoral current crossing the pier heads, the fluvial matter would remain suspended until it was far removed from the entrance. With this object in view, the north pier was designed to be 5,850 feet in length, and the south pier 4,310 feet; their general directions to be E. by N., so as to shelter the port, and to allow vessels to enter during every onshore wind. They were to be constructed of "pierre perdue," surrounded by solid masonry and ashlar work, carried to the height of six feet above the water line; and their cost was estimated at £300,000 or £30 per lineal foot. The south pier was designated to be considerably shorter than the north pier, for two reasons; first it was considered unnecessary, and indeed undesirable that the piers should run parallel to each other until the bar was reached; and advantage was therefore taken of the south lip, beyond the opposite shore, to commence the south pier nearly 1,000 feet seaward of the commencemement of the north pier; secondly in order to shelter vessels entering and leaving harbor during the prevailing N. and N. E. winds, the north pier was designed to overlap the south by 600 feet, a length equal to the normal width of the river. Such was the first design, and, as the second only differed from it in the length of the piers, and in their comparative provisional character, reference need now only be made to these differences, without further allusion to the actual trace of the works, which was identical in both cases.

The author, having received the instructions of the Commission, proceeded to design works of a minimum section with regard to strength, in order to prolong the piers as far seaward as possible, for the smallest sum, and with the greatest speed. The problem submitted to him was to provide guiding works, which, for a sum limited to £80,000, should be carried out so far as to give an increased depth of at least two feet, and should have solidity sufficient to resist uninjured the attacks of a notoriously tempestuous sea, for a period of six or eight years. This duration of time was based on the assumption, that during such an interval, either the St. George would be opened or it might be considered expedient to limit the improvement of the Danube, to rendering permanent the provisional works at the Sulina.

The first idea which naturally presents itself to the mind, in designing such moles, in a country where stone is obtainable, and where skilled labor is only to be had at great cost, is the simple expedient of throwing down stones at random, along the line of the projected works. On consideration, the following objections to this plan caused the author to reject it. First, if carried to the surface of the water, the upper stones would be liable to displacement during gales, and the cost of such a mass of material would greatly exceed the limits of the proposed expenditure.

Secondly, supposing the stones to be only carried up within three or four feet of the surface of the water—a plan actually proposed to the commission by one of its technical advisers—the pier would form dangerous reefs, on each side of the entrance, and the escape of the water issuing from

the river over these reefs would greatly diminish the good effect sought.

It thus appearing that the employment of stone by itself, would not answer the purpose, the author turned his attention to the employment of fir timber, which can be purchased in any quantity, and of any size, at from 3d. to 4d. per cubic foot.

He then found that by combining third-class rubble with timber, he could construct the required length of pieces for a sum not exceeding the prescribed limits.

The first plan was to construct cribs from 30 to 60 feet long, of timber 12 inches square, firmly fastened together; to load them with stones and to sink them at intervals of 20 feet along the line of works, the whole being protected at the foot by rubble-stones. This plan, however, was not adopted, as the cost of the cribs, owing to the difficulty of fixing them, and their settlement in the sand, would have exceeded the original estimate. Choice was finally made of a structure composed of piling and "pierre perdue" surmounted by a timber platform 14 feet wide, strengthened by solidly-constructed cribs of the same width.

The works were commenced, April 21st, 1858. A temporary staging fixed on piles, driven by ringing engines, worked from barges, was run out from 200 to 300 feet in advance of the permanent piling; and although, during violent gales it was partially destroyed, the repairs were rapidly effected during fine weather.

The staging supported nine crab engines, each working a monkey, each weighing 15 cwts., and driving down daily, on an average, a pile 13 inches square, 16 feet into the hard fine sand of which the bottom is composed. By these means three rows of three piles each, at square distances apart of seven feet, were frequently driven in one day. They were then immediately secured by double longitudinal walings 12 inches by six inches, and double cross ties 12 inches by four inches, and 15 feet long, the whole being surmounted by two tram-pieces six inches thick, and planking three inches in thickness, at four feet above the level of the sea. From this permanent platform, the close piling on the side next the sea was driven, by six similar crab engines, following closely on the open seven feet bays in advance. The daily rate of progress during fine weather was 20 feet; and no sooner had this length of sheet piles been placed, than stones were thrown down to protect its footing in the sand, which without such protection, was liable to be washed away to such an extent by the beat of the sea, as to endanger the stability of the exposed close piling although driven 14 feet into the ground; and so serious did this scouring action become, when the skirt of the bar was reached, along the line of open piling immediately beyond the sheeting, that although confined to that locality, it threatened at one time to demand double the quantity of stone originally estimated.

As an instance of the power of this action—the result of attacks solely from the sea, unassisted by the river current—it may be mentioned, that a crib, 30 feet by 15, sunk in a position in nine feet of water, loaded with 130 tons of stone remained for nearly one week without settling $\frac{1}{100}$ of an inch. No sooner, however, was the foundation attacked by a heavy sea than the crib sank bodily four feet deep, in three days, and then only came to a bearing owing to the stonework, which in the mean time had been deposited around it almost to the level of the water, having arrested the scour. In the first instance bags of sand were made use of, to fix the bottom and to fill the holes which had been scoured out between the open piling. This expedient was economical, as long as old sacks were supplied at a merely nominal price; but when the supply failed and the cheapest kind of new canvas sewn into sacks was substituted, it was found, that bulk for bulk, the sand-bags cost as much as the stone without answering the purpose as well, thereupon the following plan was adopted, for 400 feet. Long rafts of unsquared timber, laden with fascines and stones, were sunk between the exterior open piles, as well on the river as on the sea-side, so as to cover the base of the embankment with a layer of four feet in thickness.

This arrangement was economical, and would have succeeded perfectly, had time been no object; but as the sinking of the fascines could only be accomplished during perfectly calm weather, the progress of the work became so slow as to necessitate the employment of some other system, which would insure greater rapidity of execution. Recourse was then had to a plan which answered as well in every respect, and by means of which the author has been able to complete the works within the original estimate, and in less time than at first specified.

The open pile-work was advanced with all possible expedition, and the proposed seat of the advancing pier was paved with stones delivered from barges.

This pavement withstood the attacks of the sea, and offered no great obstruction to the penetration of the street piles, which, without being shod were frequently driven 10 feet into the ground, after having been driven through eight feet of rubble-stones.

In throwing down the stones from the barges, care was taken to pitch them close to, and equally on each side of the sheet piling, until the stone-work showed itself above the water line; and then, after the wedge-shaped upper portion had been distributed over a wider base, by the action of the waves, to repeat the same process, until the slopes found their angle of repose.

In this way no more stone was employed than was absolutely necessary for the stability of the work, which, when completed, might be described as a mass of closely-packed third-class rubble, resting on a broad base, and narrowing upwards to a level slightly below the surface of the water, at which point it became a mere ridge resting against the close piling; the side slopes of its section varying from two to one near the pier heads, from one to one, and 1½ to one, near the shore. The piers were completed on the 31st July, 1861, and the time employed in their construction was thirty-one months, exclusive of three winter months in each year, but inclusive of two hundred and seven days, during which it was impossible to work on account of stormy weather. The length of the north pier is 4,631 feet, and that of the south pier is 3,000 feet, and the depth of water in which they are built, varies from six to 20 feet.

In this construction 200,000 tons of stone, and 12,500 piles have been employed, and the cost per lineal foot has not exceeded ten guineas.

The stone which was used is a hard blue limestone, and was transported 58 miles by water, after having been, for the most part, carted two miles to the river bank at Toulcha. None of the stones were heavier than two men could lift, or less in size than a common brick, and their highest price delivered at the piers, including all charges, was 5s. per ton, and the lowest price was 4s. per ton. All the transverse and longitudinal timber, as well as the planking and fender piles, were oak, and their cost at the rate of 2s. 3d. per cubic foot. While the fir piles were delivered ready for driving for four pence per cubic foot.

The workmen, of whom there were generally 300, were composed of men belonging to upwards of ten different nations. Laborers were paid 2s. 6d. per day and carpenters 4s. 6d. per day. The foreman of the works, Mr. William Simpson, displayed an energy and ability in the execution of his duties which were creditable to him.

The earliest authentic document extant which shows the state of the Sulina mouth is the Russian Government survey of 1829.

The depth on the bar since the year 1829 has varied between the depths of seven feet and twelve feet; the least depth being found during the subsidence of high-water floods, and the greatest when the deposits lodged by these floods had been dispersed by the autumnal and winter gales. In July, 1857, when the works were commenced, the river margin of that portion of the Sulina bar which gave soundings of less than 15 feet, was 2,000 feet distant from the north promontory of the mouth, and 4,000 feet from its sea-margin. Near the centre of this long shoal the navigable channel was only nine feet deep. In November 1859, when the works had been brought to a close for the winter, the north pier had advanced 3,000 feet and the south pier 500 feet. The depth on the bar was then 10 feet.

From this period till the following April, although the works remained stationary, the depth of the channel increased to 14 feet.

As this could only be attributed to the north piers, hopes were entertained that its action would be sufficient to maintain the improvement, which unaided, it had effected. These expectations, however were soon disappointed, for during the spring and summer months, the unusually high river floods caused such a deposit at the mouth, that in August when the north pier had reached the length of 4,600 feet, or to within 30 feet of its present extremity, the depth of the bar had diminished to 9½ feet. The inadequacy, therefore, of a single pier to maintain an improved depth was fully demonstrated.

Every exertion was then made to bring the south pier into play.

Accordingly during the next three months it was pushed out 1,500 feet further, and as it was then brought to within a dis-

tance of 600 feet of the north pier, the good effect of concentrating the whole force of the river current directly on the bar became at once apparent. Thus on the 30th of November, there was a good navigable channel of twelve feet; on the 31st of December of 13 feet; and on the 28th of February, 1861, of 14 feet.

Then came the breaking up of the ice on the river, and the furious descent of the extraordinary high floods, which caused so much damage at Galatz, and submerged the whole Delta; but this time, the swollen waters being confined between the two piers, and being directed in a proper line, instead of causing a diminution of the depth, fairly swept away the remainder of the bar on to the south bank and into deep water. From that time to the present, the depth has never been less than 16½ feet, and frequently more than 17½ feet, over a navigable width of 500 feet. This result has been accomplished by works the cost of which has not exceeded the sum which was paid in one year only for lightening vessels over the bar, when its depth did not exceed 10 feet.

Nor is this the only subject for congratulation. The great gain to the shipping interest, in other and still more important respects, is incalculable. For some years an average of 2,000 vessels, of an aggregate capacity of 400,000 tons, visited the Danube, and of this number more than three-fourths loaded either the whole or part of their cargoes from lighters in the Sulina roadstead, where, lying off a lee shore, they were constantly exposed to the greatest danger. Shipwrecks were of common occurrence, and occasionally the number of disasters was appalling.

As an instance, on one dark winter night in December, 1855, during a terrific gale, twenty-four sailing ships, and sixty lighters, went ashore off the mouth and upwards of three hundred persons perished. At present no disaster is possible. Vessels may enter at any time with any wind.

Sulina, in fact, is now one of the best harbors of refuge in the Black Sea.

The summary of facts leads to the hypothesis, that if the good effects that have already been produced should now be as suddenly lost, the expenditure on the whole just described, would not have been unprofitably applied.

Fortunately, no such catastrophe is immediately impending; for the comparison of the plans of the mouth which were made by Mr. Hansford, the skillful surveyor of the Commissioners before the commencement and after the termination of the works, show that while deposits of a small extent have taken place in the interval to the south of the improved channel there have been no deposits whatever to the north.

This evidence is encouraging for the future, and sustains the position which has been so much insisted upon by the Commission, that the system of parallel piers, as applied at the mouth of the Sulina branch is the best that under the circumstances, could have been devised for an improved sea-entrance to the Danube, even with the certainty attached to it which is not denied—that to maintain the improvement, and to keep pace with the formation of new sand banks, or the growth of old ones, the guiding works must eventually be prolonged.

CIVIL ENGINEERING.

SUSPENSION BRIDGES.*

From the "Building News."

Until the completion of Hammersmith Bridge in 1824, there existed no example of this method of construction in the vicinity of London. Their history is, however, of very ancient origin, and they are adopted chiefly for spans too great to be crossed by girders or arches at a reasonable cost, or where a foot-bridge only of small span is desired. Humboldt informs us that numerous early examples exist in South America made from ropes 3in. or 4in. in diameter, formed from the fibrous portions of the roots of the American aloe. Such structures are asserted to have existed in America prior to the arrival of Europeans. Bridges composed of more durable materials also are found to have existed in these remote districts.

* Abstract of paper read before the Civil and Mechanical Engineers' Society.

An iron suspension bridge of fabulous origin is known to have existed in China. Numerous bridges on this principle are spoken of by various travellers in China, which are said to vibrate to and fro so much that persons crossing them are affected with sensations of fear lest they should come to grief while passing over. We have no record of the adoption of such structures to cross a river or valley by the Greeks, the Romans, or the Egyptians. The engineer, it is reasonable to suppose, has therefore obtained his first ideas for the construction of suspension bridges from the barbarians of America. Scamozzi mentions the existence of suspension bridges in Europe at the beginning of the seventeenth century, but as the mathematical knowledge requisite to determine their properties was not arrived at till the middle of the following century, it is doubtful whether such were constructed upon true principles. They were probably of short duration, as other writers are totally silent on the subject. The oldest suspension bridge in the United States was erected at the close of the eighteenth century. The old Winch chain-bridge, over the Tees, between Durham and York, chiefly for the use of miners, is said to be the oldest example in England. Wire suspension bridges were also made, though to no considerable extent, in Scotland at the commencement of the present century. Experiments were made by Telford when the bridge of Runcorn was under consideration, accounts of which are to be met with in various works, and their results applied to the consideration of suspended girders. Telford designed the magnificent bridge over the Menai Straits, separating the Isle of Anglesey from Carnarvonshire, and employed four sets of main chains, each consisting of four, making sixteen chains altogether, the tension in each of which was similar and uniform. Each chain was formed of five links 10ft. long, 3¼ in. wide, and 1in. in thickness, with chain plates to connect them at each end 1in. thick. Vertical rods supporting the framework for the platform are suspended from these chains at equal distances of 5ft. apart. In Mr. Drewry's excellent treatise on suspension bridges we are informed that the plan of operation in putting up the chainwork of this bridge was as follows:—"The chains were first put together in the tunnels, working up from the fastenings to the mouths of the tunnels by bringing down one link of each chain at a time, and bolting it to the one brought down before. Next, the chains were put together from the mouths of the tunnels up to the main piers, upon a scaffolding erected on the masonry between the pier and the shore, with the proper inclination for the backstays. The chains were then continued over the Carnarvon pier, hanging down loose nearly to the level of high water. This was done by suspending a cradle large enough for two men to sit in, from a crane arm set up on the top of the pyramid. The cradle was suspended by tackle, so that the men could slack it down or haul it up, to raise or lower themselves at pleasure. The links of the chain that were to be joined on to the ends of the chain hanging over the top of the pier were brought successively along the road to the front, or sea-face of the pyramid, through the arched roadway opening. Thence the link was taken up by a tackle from a pair of shears placed on the top of the pyramid, and lifted up to the height of the link it was to be fixed to, where the men in the cradle got hold of it and brought the two links together, and put the coupling bolt through them. On the Anglesey side of the Strait the chains were carried just over their saddles on the top of the pier, and their ends were retained by tackle made fast to them, and descending thence to capstans on the shore. The remaining piece or length of chain, which was to unite the two ends of the chains brought up from each shore, was laid on a raft 400ft. long and 6ft. wide, made of whole deal balks bolted together. One end of the piece of chain was first fastened to the end that hung over down to the water from the Carnarvon pier, and then the raft was floated across to the Anglesey pier, and the loose end of the chain upon it was fastened to the tackle that hung down from the pier. The tackle was then hauled up by the capstans fixed on the shore, and the chain raised gradually off the raft until the end of it was brought in contact with the end of the chain that hung over the top of the pier. The two loose ends were then bolted together, and the operation completed." The Conway Bridge is built on the same principle as that over the Menai Straits.

It is 327ft. in span, with a versed sine of curvature of main chains=22ft. 6in. There are eight chains, which were erected by means of strong rope cables reaching from top to top of towers, suporting a temporary platform. On this the chains were carried and fixed in position ; afterwards the platforms of wood were taken away, the rope cables slackened, and the chain lowered to its proper curvature. The Union Bridge, across the Tweed, was the first bar-chain bridge of considerable size erected in this country. It was designed and executed by Captain Brown. Distance between points of suspension, 449ft.; deflection, 30ft. The roadway, 18ft. wide, is supported by vertical 1in. rods, 5ft. apart, suspended from twelve main chains, arranged in couples, and forming three sets on each side of the bridge, one underneath the other. The Newhaven Suspension Pier, Brighton Chain Pier, Montrose Suspension Bridge, and other structures, were also executed by the same engineer. The Newhaven suspension pier, 700ft long and 4ft. wide, is divided into three spans, each supported by longitudinal girders, held up by vertical rods suspended from two main chains, passing over cast-iron saddles. The old Brighton pier consists of four main chains on each side, from which the platform is suspended by vertical rods, 1in. in diameter, 5ft. apart. In 1838 it suffered much damage during the storm, the roadway being carried partly away, and the suspension-rods broken. In the Montrose suspension bridge, scarcely second in point of construction to the Menai, the roadway is 412ft. long, and 12ft. wide and was suspended by 1¼in. vertical rods, without joints, 5ft. apart, from two main chains, each composed of bars 10ft. by 5in. by 1in., the versed sine of the catenary being 42ft. About ten years after its completion, about one-third of the platform gave way, in consequence of the failure of one of the suspension-rods, when rods of 1⅝ in. diameter, with flexible joints at the level of the platform (to avoid any twisting that the undulatory motion might cause) were substituted for the old rods. A system of vertical diagonal trussing, 10 ft. deep, placed half above and half below the platform, was also adopted, to prevent undulation, as well as consequent oscillation arising from one side being raised by the wind at one end, while the lower side at the other end was depressed. In the following year (1839), the bridge over the Menai Straits was severely injured by a storm, the carriage-ways being rendered impassable, and a portion of the suspension-rods torn away. The motion was stated to have been greatest about midway between the points of suspension and the centre of the bridge. The Hammersmith suspension bridge was executed by Mr. Tierney Clark. The large span is 422ft. 3in., the versed sine of the catenarian chain being about 29ft. The platform is divided into a carriage-way 20ft. wide, with footpaths on either side 5ft. wide. Two of the eight main chains on each side of the carriage-way have links consisting of six wrought iron bars 8ft. 10in. long from centre of the eyes, 5in. wide, and 1in. thick. The other chains on the outside of each footpath have only three lines of bars of the same dimensions in each link. The total length of the bridge from abutment to abutment is 822ft. 8in. The links are fastened to holding-down plates embedded in brickwork in abutments, pasing through tunnels 3ft. wide for the large chain and 2ft. wide for the small side chains, which pass down at the same angle as the chains of the central opening. In February, 1869, questions were asked in Parliament as to the stability of Hammersmith Bridge under the extraordinary strain brought to bear upon it on occasions such as the University boat-races, when not only is every available standing-room occupied, but hanging on the chains and climbing the suspension-rods are indulged in, regardless of the certainty which Tierney Clark never foresaw, namely, the uncommon and unusual load brought to bear upon his bridge.

To test the condition of the bridge, then, Captain Tyler on the part of the Government, with Mr. R. M. Ordish on the part of the Hammersmith Bridge Company, were respectively appointed to investigate in a thorough and practical manner its actual efficiency. This was done by removing at random some of the suspension-rods, as also taking a spare cross-girder which (cast at the same time—probably 1820—as the others) had been lying as a superfluous one in the dampness of alluvial soil ever since. The quality of the iron was carefully tested by Mr Kirkaldy, and the results were satisfactory. The suspension-rods, 1in. square,

withstood a strain up to 18 tons. The cross girders are of substantial 1¼ inches metal in the web, 3ft. 6in. between outside suspension points, 17 inches deep at centre, tapering outwardly to 8½ inches at those supports. The inside suspension-rods are keyed five feet nearer centre of girder, where the girder is 12 inches deep. These measurements were accurately taken. Owing to the misfortune which happened to the spare girder while being conveyed, owing to the carelessness of the carter, the girder being laid on its side, the jolting and jerking caused it to break of its own weight; hence only the quality of the metal was ascertained, upon which deductions and calculations were based, and a knowledge of its strength arrived at satisfactorily. In regard to the saddles and rollers of the chains, it might be asked if rollers are of any practical service whatever? Would not the friction of the rollers be so great as to require the tower itself to ease before the rollers revolved? It is noticeable that the Hammersmith Bridge rollers appeared rusted into their saddles or bearings, there being, notwithstanding, evidence of the chains having rubbed their under surface upon the rollers. A bridge of similar construction by the same engineer, consisting of four main chains composed of flat bars, was erected at Marlow some years ago. The total length is 426ft., and the deflection of the chains 18ft. 6in. In the Norfolk Bridge, of 284ft. span, there are three lines of chain each side, the deflection being 20ft. 2in. Here the backstays are not placed in the same angle as chains in the centre span. In the Broughton Suspension Bridge, near Manchester, of 145ft. 6in. span, with a deflection of 12ft. 6in., the platform is held up by two chains on both sides of the structure, resting on cast-iron suspension frames, in which due allowance is made for expansion and construction.* The Tiverton Suspension Bridge, over the Avon, near Bath, is supported by suspending bars averaging 2in. by 1in. placed 2ft. 6in. apart, and keyed into a cast-iron plate fastened to the towers. The bridge of Micklewood has its platform supported not suspended; its span is 103ft. The cross girders are secured together by cross bracing, and rest upon iron frames, which are supported by chains on each side. The widest suspension bridge ever attempted in England is at Clifton. It is 702ft. 3in. in span., and 31 ft. wide. The versed side of the curved chain is 70ft. There are three chains supporting wrought-iron main girders, with cross girders of open work. The chains were carried upon the piers by saddles of wrought iron resting on cast-iron bed-plates fixed on cast-steel rollers. A girder bridge for the Charing Cross Railway being decided to be erected in place of the old Hungerford Suspension Bridge, the chains were purchased for a moderate amount, and adapted for use at Clifton. Mr. Barlow, in his account of the Clifton Bridge says, "The links were arranged in the old Hungerford Bridge so that the joints of the links in the upper chain were opposite to the middle of the links of the under chains, and the suspension-rods were carried by a jointed link in such manner that half the weight was borne at the point of the one chain, and the other half by the middle of the links and the other chain. In this mode of hanging the suspension-rods a transverse strain of considerable amount was brought upon the middle of the links of the chains. In the Clifton Bridge this was avoided. The suspension rods transmit their strain to the chain only at the joints. The result is that the links of the chain have no other strain upon them than that of the direct tensile strain in the direction of their length. The duty of maintaining an equal action upon all three chains in supporting the roadway is performed by the strength and stiffness of the longitudinal girders. The suspension-rods are attached to the longitudinal girders, each rod being furnished with a double adjusting screw at the lower extremity." The links were tested both in the Hungerford and Clifton bridges to a strain of 10 tons per square inch. The temporary staying necessary for their erection consisted of eight ropes of iron wire, each rope calculated to sustain 35 tons. Six of these supported a platform staging upon which the links were supported by packing pieces until the connection in the centre of the chain was made, when it was allowed to take its own bearing. The remaining two ropes were placed above the links to serve as a handrail on either side and were attached to the platform below by strong hoop-iron.

* In 1831 this bridge sustained severe injury by the vibration produced by a company of sixty soldiers marching over it.

Another rope was also fixed to carry a travelling framework supported on wheels, by means of which the links, tools, &c., could be conveyed from any one part of the work to any other part. The weight of the chain between piers was 550 tons. The Chelsea Suspension Bridge 704 ft. long, is divided into a central span of 333 ft. and two side spans of 166ft. 6in. Its width is 47ft. The chains are four in number two on each side, consisting of links 8in. wide, in lengths of about 16ft. from center to centre of pinhole. The deflection of the central portion is 29ft. The chains are carried over saddles resting on fixed massive cast-iron cradles, supported on cast-iron columns cased with ornamental cast-iron work, and weigh altogether 340 tons. At the abutments the chains are diverted to their moorings through tunnels placed at angle of 155 deg. with a horizontal line. Four temporary chains of 2in. wrought-iron rods, placed on each side of the permanent chain, were thrown across for their erection, by means of which the bridge-links were hoisted and fixed. In addition, four similar chains placed below these were thrown over to support a timber platform for the workmen. The suspension-rods are each divided into two at the chains by means of a crosshead or short bar fixed to the centre of the suspension-rod, and at the ends to two short rods, one of which is connected with the upper chain, and the other with the lower. By this means each chain is made to take an equal strain, since the leverage is the same on either side. We see, then, that in most suspension bridges the platform is suspended by vertical rods hanging from chains stretching across from tower to tower, by means of which the whole weight of the roadway and the moving load, generally estimated at from 70lb. to 90lb. per square foot, is transmitted through the chains to the piers. Mr. Dredge, of Bath, some years ago invented the taper-chain suspension bridge, with the object of rendering the roadway free from the effects of undulation and vibration. The invention consisted in supporting a great portion of the roadway directly from the standards on each side, thus leaving a diminished tension due to the chain, and in having the chains of such strength and size at the points of suspension as would suffice to support the maximum fixed or moving load to which they are at any time likely to be subjected, and from thence gradually tapering to the centre of the bridge, where the strain would necessarily be small compared with that at the piers. The roadway is suspended by rods inclined at angles varying in magnitude from the abutments to the middle of the bridge, where the inclination and strain upon the rods attain their lowest value, instead of, as in the old system, hanging vertically from the main suspending chains The Victoria Bridge at Bath, erected in 1836 150ft. in span, was the first constructed on this principle, and several specimens can be seen in Regent's Park at the present time. The largest suspension bridge in the old world is that at Fribourg, which is asserted to be 880ft. in span. The Niagara Railway Bridge is 820ft. from centre to centre of towers. To render a suspension bridge as stiff and rigid as a girder bridge has for some time engaged the attention of the profession. Various improvements have been suggested to maintain the true catenary or curve of a strain and thus reduce the undulation arising from flexibility. Longitudinally a bridge is flexible in regard to the chain and roadway, and becomes slightly altered in its outline whenever a heavier moving load is passing over one end than at the other, or the same may arise from excessive pressure of wind above or below. In the bridge over the Thames at Lambeth, the wire-rope curved chain is braced down to the platform by diagonal ties and vertical struts. This structure has been much condemned by architects, but it is the cheapest bridge built across the Thames. It is however, to be regretted that the material in the towers was not disposed of and arranged in a more artistic manner. A similar arrangement has been carried out in a foot bridge over the main at Frankfort, where the girder is hinged at centre of span. Another plan, adopted in a railway bridge at Vienna, has been to employ two chains placed one over the other, and braced together by diagonal bracing, or to connect the two points of the curved chain most likely to effect any alteration in form by short straight chains with the base of towers. The latest improvement in this direction is Mr. Ordish's rigid suspension principle, consisting of a combination of inclined straight chains retained in position by curved chains, and forming as inflexible a system as possible for maintain-

ing the platform and moving loads. The load on the curved chain being always the same, the curve is retained under all circumstances of loading without variation. The fixed load is supported by inclined straight chains, which are maintained in straight lines by vertical rods suspended from the curved chain. These chains also sustain the moving load, and being thus arranged require nothing extra, such as bracing, to prevent any kind of deformation in the event of the structure being unequally loaded. Direct tensile strains only are induced by the distributed loads and conveyed by these straight chains to the abutments without disturbing the stable equilibrium of the structure.

Deflection is common to all bridges, of whatever construction, and arises from the elasticity of the material employed. With the exception of deflection, Mr. Ordish's rigid suspension-bridge has been found to be theoretically and practically rigid. The main or parapet girders are continuous in the centre span. The principle may well be adapted for sites where a single span only is required, or where two river-piers as in the case of the Francis Joseph Suspension Bridge (opened in 1868), over the river Moldau, at Prague, the ratio of the length of the centre opening to the side spans being such that, in the event of one or both side-spans being loaded while the centre span is unloaded, the weight of the structure in the centre opening shall balance the total weight of the structure and load on the adjoining spans. The proportion will of necessity vary with the total length and weight of the requirements of any bridge. In the case of the Prague Bridge the proportion is about 3 : 1 to satisfy the conditions of unequal loading. The bridge is 820ft. long by 31ft. wide. The centre span between centre of towers is 492ft. The wrought-iron parapet-girders are continuous from end to end, due allowance being made for expansion and contraction, and are supported by means of straight inclined steel chains at distances of 82ft. apart, which are retained in position by a light curved chain. The only deflection arises from the elasticity of the material, and is independent of any unequal loading, as in former suspension bridges. The inclined chains are a fixed unchangeable load, and can have no tendency to alter the form of the curved chain when once suspended in their proper positions. The cost of bridges on this principle does not exceed that of ordinary suspension bridges, which embraces the principle longitudinal stiffening-girders, combined with curved chains, and possesses the advantage of being more adapted to railway traffic, and capable of sustaining the greater partial loadings at various speeds to which a railway bridge is subject. Roebling has obtained a similar effect in his large American bridges by straight inclined chains connected with the girder at the most dangerous points, and extending to the saddle at the top of towers ; many of these structures are employed for railway traffic. In 1862 Mr. Ordish designed a bridge of 82ft. span for a proposed railway over the Thames near the Tower. The design met with approbation of Mr. W. H. Barlow, who considered the principle applicable to spans of 1,100ft. In 1863 the new Albert Bridge was designed upon the same principle, and this is now in course of construction. Shortly after the passing of the Act, the works were commenced, but remained in abeyance for some time, until the line of the new Chelsea Embankment had been arranged, so that a better connection with the shore might be made than exists on the Surrey side of Lambeth Bridge. In the mean time designs were submitted by a few other engineers upon different principles, among which was an exceedingly novel one by Captain Roberts, who proposed to abandon the suspension principle, and span the river by ropes composed of strands of wire (covered over with a selvage of ¼in., enveloping each rope, to prevent oxidation) passing over two pairs of cylinders between the abutments. It is not difficult to prove that a cord or rope stretched straight between two fixed points would bear no very great transverse strain without breaking, supposing the cord to be inextensible, and not to have an infinite longitudinal resistance, and that it would be impossible to draw the rope into a horizontal position, since every material cord or wire, being composed of particles, possesses weight, and would be acted on by the natural force of gravity. Our contemporary, *Engineering*, recomended Captain Roberts to study the involuntary verse in Dr. Whewell's "Mechanics":

> "There is no power, however great,
> Can stretch a cord, however fine,
> Into a horizontal line,
> That shall be accurately straight."

THE ECONOMY OF THE BLAST FURNACE.

BY PROF. FRED. PRIME, JR.

Transactions of American Institute of Mining Engineers.

To an association like the one before which I read this paper, few questions can be more important and constantly recurring than the following, viz: "What economy can be effected in the manufacture of American iron?" And it is the one with which I purpose to deal in this paper; premising, however, that my object is merely to indicate the direction in which an answer should be sought for, rather than to give it myself. This subject may be divided into two parts, "Economy in the production of pig-iron," and "Economy in the manufacture of wrought-iron;" but it is to the former alone that I shall confine myself this evening.

Of late years the improvements inaugurated in the Cleveland District have excited the wonder and admiration of the iron world. Instead of 30, 40 and 50 feet furnaces, the iron-masters of this district have taught us to build them of 70 and 80 feet, which last height is, I believe, the greatest yet reached in the United States.

The first object of the furnace manager is, *cæteris paribus*, to obtain the greatest amount of metal with the least consumption of fuel. So long as gases are ecaping from the furnace-throat of such a nature and temperature as to be capable of reducing the ore being treated, we know that heat, or in other words, fuel is lost. The first point to be settled is, at what temperature each ore commences to be reduced.

Bell has shown that in the Cleveland ore this process begins at 424 deg. Fahr., while he holds that, in general, sesquioxide of iron is deoxidized at all temperatures between 302 deg. Fahr. and a bright red heat, but that it is never absolutely complete. And he shows that the reduction of ores containing sesquioxide of iron is dependent not on their chemical composition, but on their molecular condition, and the rapidity of the current of gases passing over them, and the deoxidation and carbon deposition are at a maximum at about the temperature of melting zinc, 783 deg. Fahr. Now, to ascertain at what temperature the various magnetites, hematites, and limonites of this country commence to be reduced it would be necessary to make a series of experiments on the subject with native ores, in the performance of which no very great expense would be incurred. This having been done, the next step should be to ascertain the temperature and composition of the escaping gases, in order to see whether all the work that was practicable had been performed by them in the way of deoxidizing the ores. This, of course, would vary very much with the different coals and varieties of each. Should it be found, for example, that the gases when escaping at the furnace-throat were still capable of deoxidizing the ore, then the inference would justly be that the furnace was not high enough, and that fuel was being lost, and it would be a commercial question, as I. Lowthian Bell states it, whether the additional expense of enlarging the furnaces would be sufficiently paid for by an improvement of the operation or an increase of work effected. Where anthracite is used in the blast-furnace, there need be comparatively but little apprehension of the burden crushing the coal, except by the decrepitation of the latter, and I would call the attention of those persons present who direct such furnaces to the question, whether they have ever instituted comparisons in regard to the economy of anthracite furnaces when both the pressure and amount of blast are increased? Anthracite, although equal to coke as a fuel in the amount of carbon, requires a much greater pressure of blast for its perfect combustion, which should be equally distributed through a large number of tuyeres, and I would suggest that iron-masters should endeavor to ascertain the fact, whether with such a dense fuel, considerable economy might not be attained by increasing the height rather than the diameter of such furnaces. We have in this country many open burning coals, which either do not coke at all, or else afford a very tender coke in ordinary ovens. In Great Britain the Ferrie self-coking blast-furnace has been introduced for the purpose of coking the fuel in the furnaces, and at the same time relieving the coke of a portion of its burden. In order to do this a furnace eighty-three feet high is divided, for a distance of twenty feet below the space required for the cup and cone, into four

compartments, by vertical walls supported on arches and radiating from the centre. Both these and the circumferential walls are pierced with flues, so that a portion of the gases taken from the top can be led down to the level of the bottom of the compartments and—receiving a supply of air through gratings in the external wall of the furnace—be ignited and consumed in the flues traversing the partition walls and surrounding the compartments, the draft through these flues being assisted by chimney-stacks at the top of the furnace. Time does not permit me to give any further details, for which I must refer you to "Engineering" of June 16th, 1871, and Volume I of "Journal of Iron and Steel Institute." Suffice it to say, that in Lanarkshire district, the extraordinary result was obtained of saving a ton of coal to the ton of iron made, and also about 2½ cwt. of ore. I. Lowthian Bell, who at first attributed the entire saving to the increased height of the furnace, subsequently changed his opinion and acknowledged that a portion of it was due to the combustion of the gases in the chambers.

Another point to which I wish to direct your attention is the manner of taking off the blast-furnace gases from the top of the furnace. It is a well-known fact that the gases have a tendency to escape up the sides of the furnace, leaving, in the centre, a column of ore, fuel, and limestone untouched. The common method practiced in this country, where the furnaces are close-topped, of taking off the waste gases at the throat from the sides of the furnaces, tends to increase this difficulty by creating a draught in the direction of the sides. Consequently if the gases are taken off from the centre of the furnace above the charging hole, this tendency is more or less counteracted. There can, however, be no doubt that taking off the waste gases from the centre of furnaces tends to prevent the latter from scaffolding, and also to economize fuel. Lurman's patent cinder-tap is probably so well known to you all that mention of it here would be superflous, although experiments at various iron-works have been made with very contradictory results.

Another point, which I cannot too urgently set before you, is the very insufficient attention paid in this country to the proper comminution of ores. When small and large pieces of ores are thrown indiscriminately into the top of a furnace, it must necessarily work very irregularly, owing to the fact that the smaller portions are reduced and carbonized before the interior of the larger ones has begun to be reduced. The consequence of this is a very irregular yield in the different qualities of iron. This would to a great extent be ameliorated, if not entirely prevented, by bringing the ore to a nearly equal state of division by passing it through some ore-crusher or breaking it with hammers. As regards the calcining of ores, but very little has been done in the United States. It is true that in some places black-band is calcined in open heaps, in order to increase the percentage of iron, while in others, as at Johnstown, coal-slack is intermingled with the impure carbonate of iron on a hillside, and the mass of ore roasted. But the important advantage of rendering the magnetites and red hematites of this country porous, and consequently more easily reduced in the blast-furnace by calcining them in kilns, has, I believe, only been tried at Ringwood, N. J., with what results I do not know; but it is claimed for the Westman furnace, which is the kind built there, and is heated by a portion of the blast-furnace gases, that it renders ores porous, however dense they may be. Of course where the ores contain water a great advantage is gained in thus removing it before it passes into the blast-furnace, where heat is rendered latent by its conversion into steam, causing a decrease of temperature in the upper portion of the furnace, or necessitating the use of more fuel. In many furnaces it would be possible to utilize a portion of the gases now lost in roasting the ores. Of course it is a purely commercial question whether the roasting of the ores would pay, but I am convinced that in many localities it could be profitably done, especially by using coal-slack for this purpose. Experiments in this direction will undoubtedly be made before long, and and if coal-slack cannot be directly used, as in the case of anthracite, some method will be devised for converting it into carbonic oxide outside of the calcining-kiln, and, if necessary, a certain proportion of lump coal may be added to the ore in the interior of the kiln. By running the calcined ore, while still hot, to the top of the furnace and passing it into the furnace, the decrease in temperature which always takes place when a fresh charge of cold ore and flux is added, would in a great measure be obviated.

Another point to which I wish to allude is the proper construction of hot-blast stoves. Mr. Bell believes that a very high temperature of blast is not requisite, and that when a temperature of 900° to 1000° Fahr. has been obtained, the maximum has been reached. But Durham coke and Cleveland ore are diffierent from anthracite coal and magnetite or hematite, and it seems to me that we have no right to assume *à priori*, that the conditions which are to be the best in the Cleveland district will also be the most suitable for the fuels and ores of the United States. I believe that by increasing the temperature of the blast considerably above that actually attained in this country, we shall effect a very palpable saving in the amount of fuel now necessary to produce a ton of pig metal, the temperature to which the blast may be heated being necessarily limited by the power of resistance offered by the iron pipes. The very common practice here, of permitting the hot gases to rise up vertically between the limbs of the U-shaped pipes, is a very imperfect method of heating the blast, the gases escaping so rapidly as to be capable of but very imperfectly communicating their heat to the iron pipes, and consequently to the blast. Leaving out of the question the application of the regenerative system as too expensive for us to experiment upon, until the English iron-masters are able to give us some satisfactory answer, let us look at our present pipes, and instead of conducting the hot gases vertically, cause them to pass in a horizontal direction, and we shall find that considerable economy will in all probability be attained; the blast will be heated to a higher degree, and consequently less fuel will be consumed. Should the hot products of combustion be found to still contain useful heat after passing once laterally through the hot-blast ovens, they might be made to return in the direction whence they came, through another oven, or be passed under the boilers. A considerable economy in fuel may be effected by simply arranging the blast-pipes in such a manner that the circles of fusion created by each shall be merely tangential and not intersecting. This may be ascertained by inserting an iron rod through each blast-pipe in succession for a minute, and when that portion of it situated in the circle of fusion is red-hot, the alteration then necessary in the position of the tuyeres is easily accomplished by calculating the space occupied by each circle. The last point to which I wish to allude this evening is the importance of consolidation. Those of you who are acquainted with the British iron trade are probably aware of the enormous capital employed, and the large number of furnaces owned by separate companies—eight being a very common number, and less than four a rarity. This is one of the means by which they can afford to undersell the American iron-masters when we have no tariff. Another advantage they possess is in the consolidation of their works, which enables them to dispense with a large number of officials otherwise necessary.

My aim in this paper has been merely to indicate what might be done as regards economy in the manufacture of iron, although some of the ideas appear to be impracticable at present; but before entering upon any experiments, the first and principal question to be asked and satisfactorily answered is: Will the alteration of the furnaces, and other expenses therein involved, *pay* in the end?

TRANSFORMATION OF IRON INTO STEEL.

By M. Boussingault.

From "Iron."

Iron is transformed into steel by cementing it in charcoal. The process is well known; and I shall merely mention that the metal, in bars of one to two centimetres thickness, is stratified with powdered charcoal in fire-brick boxes having a capacity of 4.9 mc. Two boxes, in one furnace, contain about 27,000 kilogrammes of iron and 3500 kilogrammes of brasque. A cementation (reckoning heating and cooling) lasts about a month. On coming out of the boxes the iron is found altered in appearance and constitution. Its surface is covered with vesicles or blisters, varying in number and size. It has lost its granular or fibrous structure, its characteristic bluish tint, its

tenacity. "Blistered steel," as it is called, is hard and brittle; its grain gives a yellowish or grey reflection, more or less deep according to the degree of carburation. When the carburation reaches a maximum the steel presents, on fracture, an undulated arrangement, with the whiteness and brightness of silver.

I have endeavored (continues the author in the *Comptes Rendus*) to determine the nature and the quantity of the substances acquired or lost by the metal during cementation. I found the task no easy one; and I devoted a considerable time to examination of various processes for determining the various elements which enter (often in extremely small proportion) into the composition of bar iron and steel. The great difficulty was to determine the iron with a precision equal to that attainable with carbon and silicium. I succeeded in estimating the iron to nearly 1-10th or 2-10ths of a millimetre, by M. Marguerite's volumetric method; on the condition, however, of employing, to determine the oxidation of one gramme of metal, a solution of permanganate of potash sufficiently dilute to occupy a volume of 340 to 350 cubic centimetres; 1-10th of a cubic centimetre thus showing the presence of 2-10ths to 3-10ths of a milligramme of iron.

First Experiment.—Two pieces (Nos. 1 and 2) were cut from a bar of iron from puddling of cast metal obtained with wood charcoal, by treatment of a mixture of spathic iron and hematite, from the mines of Ria (Eastern Pyrenees). After scouring, they were introduced into a cementing box, No. 1 into the part that would probably be least hot; No. 2 into the hottest part. After cementation the bars showed the usual protuberances, the surface between these presenting a multitude of small points, visible only with the microscope. The whole surface was coated with a uniform fine pellicle of graphite. The following is a *résumé* of the experiment:—

Ria Iron.	Weight of Bar.	Iron.	Carbon.	Silicium.	Sulphur.	Phosphorus.	Manganese.	Undetermined substances.
	gr.	gr.	gr.	gr.	gr.	gr.	gr.	gr.
Bar No. 1.								
Before cementation..	4949.55	4905.00	5.84	5.20	0.59	4.95	10.99	16.98
After " ..	4994.20	4904.30	49.69	5.34	0.30	6.24	10.99	17.33
Difference.....	+44.65	−0.70	+43.85	+0.14	−0.29	+1.29	0.00	+0.35
Bar No. 2.								
Before cementation	5124.00	5077.88	6.05	5.38	0.62	5.12	11.27	17.57
After " ..	5199.60	5077.41	78.62	6.24	0.26	6.76	11.33	18.98
Difference	+75.60	−0.47	+72.57	+0.86	−0.36	+1.64	+0.03	+1.41

In both cases the increase of weight experienced by the bars exceeded the weight of carbon fixed. The silicium, phosphorus, and undetermined substances acquired, weighed more than the iron and sulphur eliminated.

Second Experiment.—(With Swedish Iron).—A fragment of bar bearing the mark L was placed in the cementing box after scouring. This iron, considered as of excellent quality, had a very fine grain. After cementation I counted thirty-five pretty large blisters, and there were numerous small vesicles, hardly visible to the naked eye. The interior presented on section was silver white. The following is the *résumé* of the experiment:—

Swedish Iron.	Weight of Bar.	Iron.	Carbon.	Silicium.	Sulphur.	Phosphorus.	Manganese.	Undetermined substances.
	gr.	gr.	gr.	gr.	gr.	gr.	gr.	gr.
Before cementation..	2000.45	1989.45	6.00	0.62	0.30	1.14	1.80	1.44
After " ..	2026.22	1989.14	32.01	0.61	0.10	1.32	1.42	1.62
Difference	+25.77	−0.31	+26.01	+0.29	+0.20	−0.18	−0.38	+0.18

The increase in weight of the bar was a little inferior to the weight of carbon fixed.

One might ask whether the small differences given in these *résumés* did not arise from errors of analyses, which, while small, are necessarily multiplied by large numbers; the results of determinations made with a few grammes being, in fact, applied to bars of metal of 1 to 5 kilogrammes? Without doubt, we can understand how the iron, independently of carbon, takes, in being cemented, some silicium and phosphorus which have pre-existed in the ashes of the wood charcoal, that it parts with sulphur, and traces of arsenic which escape determination; but it would seem that in a cemented bar one must find all the iron that it contained before its cementation, inasmuch as it does not appear in what state that metal could be eliminated. Still, in all three observations, there was a loss of iron, very slight, indeed, but constant.

For the iron of Ria No. 1 it was about	0.00014
For the iron of Ria No 2 it was about	0.00008
For the iron of Sweden it was about	0.00016

To annihilate, or at least attenuate, the influence of errors of analyses, and especially to decide if, really, some iron might be expelled, it was resolved to determine, first of all, the carbon in the whole of the pure iron to be cemented, and then, after having ascertained the increase of weight, to search for that metal in the cement. As regards carbon, the error committed would no longer be amplified; but it was necessary to operate with small quantities of iron, an inconvenience remedied by use of a balance showing 1-10th of a milligramme.

Cementation of Pure Iron.—The iron, tested by the most delicate researches, was shown to be quite pure. The metal had been melted in a porcelain tube, traversed by a current of purified hydrogen gas, then drawn out in wire. A spiral of wire was cemented, during four hours, at a bright cherry red, in powdered wood charcoal, previously calcined. After cementation, the iron was slightly graphitic at the surface, which presented no blisters. The grain showed small brilliant facets.

	Gr.
Pure iron	1.6878
After cementation	1.7111
Increase	0.0233
In the whole cemented spiral was found.	
Combined carbon	0.0223
Graphite	0.0008
	0.0231

The increase of weight from cementation exceeded by 0 0002 gr. the carbon fixed. This difference is probably due to some substances from the charcoal ashes, so far, at least, as it does not result from the very small quantity of iron eliminated. Several experiments showed, indeed, that the ash of charcoal cement acquires a little iron; the original iron has often been doubled. It is probable that the iron is removed in the state of chloride, there being alkaline chlorides in the charcoal. The fact is, that on mixing a little marine salt with the cement, the ashes left by the charcoal then contain a considerable proportion of iron.

Elimination of Sulphur During Cementation.—It will be seen from the *résumés* given above, that the iron lost more than half the sulphur it contained before cementation. Analyses made in my laboratory prove that this elimination is constantly produced. During the fusion of blistered steel to obtain cast steel, the elimination continues. This is how cast steel of good quality contains no sulphur, or very little of it. M. Boussingault proves this from various analyses. Thus it appears that the steels considered of superior quality are really formed of iron and carbon. They are generally free from phosphorus, and the manganese, like the silicium, occurs in a proportion rarely exceeding 1-1000th.

HEAVY LOCOMOTIVES.

From "The Engineer."

In our impression for Feb. 9th, 1872, will be found an article describing an experiment carried out with a Fairlie engine on the South Yorkshire Railway on what is known as the Dropping Well incline. We shall not recapitulate the particulars of that trial. It will suffice to say that the engine, with four 15in. cylinders 22in. stroke, pushed a train weighing 371 tons before it up inclines of 1 in 32 and 1 in 50, and round S curves of as little as 7 chains radius. We refer to the experiment here because the actual work done represented at the time one of the great-

est performances of a powerful locomotive, and as such it affords an excellent example of the maximum duty to be obtained from an essentially heavy type of engine. Why we use the words "essentially heavy" we shall explain presently. Great as the performance of this engine was, it has been nearly, though not quite, equalled by a still larger Fairlie engine, constructed by the Yorkshire Engine Company for the Mexican Railway. This engine, called the Hidalgo, has four cylinders 17in. in diameter and 20in. stroke, with twelve wheels arranged in two bogies, and coupled in groups of six. The total heating surface is 1729 square feet; the grate surface is 29 square feet; the water-tank holds 2000 gallons, and the coal bunkers 30 cwt. of coal, while crates for wood are provided possessing a capacity of 400 cubic feet. The total weight of the engine in running order is 62 tons, and the tractive force at the rails is, with a mean cylinder pressure of 90 lbs., 21,940 lbs., and with 100 lbs., 24,200 lbs. Thus every pound of pressure on each square inch of piston represents 242 lbs. of tractive force, the wheels being 3ft. 6in. in diameter. On Thursday last this engine was tested on the Dropping Well incline. She pushed before her a train consisting of twenty loaded coal trucks, three vans, and one composite carriage; about fifty passengers were disposed on the engine and in different parts of the train. The whole estimated load was 326 tons. Half-way up, owing to the slippery state of the rails, the pressure of steam fell to 110 lbs., and the train came to a stand. In eight minutes the pressure rose to 140 lbs., and with this pressure the engine started the train on an incline of 1 in 26 and on a curve of 7 chains radius. Later in the day two wagons, representing a load of 26 tons, were taken off, and with the remaining load of just 300 tons the engine traversed the whole distance from Lanes-lane Station to the Dropping Well Colliery, a distance of 2¼ miles, in 9½ minutes, or at the rate of about 14 miles an hour. The engine, we may add, is fitted with the Westinghouse brake, which served to control the speed of the train down the incline very effectually.

We may now proceed to analyze this great performance, and to deduce one or two conclusions. It will be well to state that we were unable, although invited, to be present at the trial, and the figures we have put before our readers are those which have been published in a daily contemporary, and as their accuracy has not been impeached by the Yorkshire Engine Company we must accept them as official. The moment we proceed to sift them, however, we encounter a very serious difficulty, the nature of which may be explained very briefly. Let the facts be carefully borne in mind. The Hidalgo is stated to have stopped on an incline of 1 in 26. with a gross load of 326 tons, and 110 lbs. of steam. This could not well have represented more than 90 lbs. average cylinder pressure, or a tractive effort, on the showing of the builders, of, say 22,000 lbs. But the gross load—that is, the weight of the engine and train—was say 730,000 lbs. Therefore the traction effort of the engine was only $\frac{730}{22} = 33.18$, or, in other words, one thirty-third of the whole weight of the train. The engine came to a stand, as a matter of course, on an incline of one in 26, where the resistance of gravity alone equalled one twenty-sixth of the gross load. When the pressure was raised 30 lbs. she proceeded. This represented an additional cylinder pressure of, say, 30lbs., or one-third more than was available with 110 lbs. steam. The tractive force of the engine was consequently for the time something like 29,000, and $\frac{730}{29} = 25$. That is to say, the maximum tractive effort the engine could exert equalled one twenty-fifth of the weight of the train, which stood on an incline of 1 in 26, sharply curved. It is hardly conceivable that under these circumstances the engine could have moved the train at all, even if we make no allowance for the friction of a perfectly new engine, which must have been something like 20 lbs. a ton, or 1240 lbs. We have the friction of the train to deal with, which, considering the nature of the curve on which it stood, could not have been less than 4 lbs. a ton at any conceivable velocity, or, say, 1350 lbs. to add to the resistance proper to gravity. The only solution of the difficulty is found in the assumption either that the incline was not so steep as it is said to be, or that the load was not so great, or that the steam power carried was more like 160 lbs. than 140 lbs. per square inch. We shall

not attempt to decide which assumption is correct; but we may point out that the particulars supplied to us at the trial in February, 1872, over the same line, make mention of no incline steeper than one in 32, and a pressure of 140 lbs. then sufficed to take 370 tons up the road. We content ourselves with putting before our readers the only deductions than can be legitimately drawn from the reports concerning the experiment before us, and we wish it to be understood that we have no desire to depreciate the performance of the engine. We simply discharge our duty when we point out that certain discrepancies exist between the reported circumstances of an experiment and the facts, to which we are led up by a very simple chain of reasoning.

We may now proceed a step further, and examine the adhesional power of the Hidalgo. The wheels carry as nearly as may be a load of five tons each, a little more when the tanks are full, and a good deal less when they are nearly empty—for 2000 gallons of water weigh 20,000 lbs., or a little less than nine tons. The tractive effort required to impel a train weighing 326 tons up one in twenty-six was, as we have seen, at least 29,000 lbs., or very nearly thirteen tons. But the engine when standing on an incline of one in twenty-six, lost one twenty-sixth of its weight. What remained for adhesion was not sixty-two tons but less than sixty tons; and as the tanks were probably not quite full, we may say, fifty-nine tons, and $\frac{59}{13}$ =4.53. Thus the coefficient of adhesion of the engine really exceeded one-fifth of the entire insistant weight on the rails, and was in all probability more nearly one-fourth of the insistant weight. This was, of course, in a great measure due to the copious use of sand. But the fact nevertheless goes far to answer an argument that we have often heard urged, to the effect that with loads as small as five tons per wheel the coefficient of adhesion is never equal to one-fifth of the insistant load. Taken for all in all, it will be seen that after every deduction has been made, the trial was very satisfactory, and we may regard it as establishing in some sense a precedent on which we may argue with confidence. Thus it may be taken as proved that with an engine weighing, with coal and water, sixty-two tons, a tractive force of thirteen tons can probably be maintained for a run of 2¼ miles; whether it could be maintained for greater distances it is impossible on the data before us to say with confidence. It is to be regretted that in carrying out such trials no attempt is made to measure the consumption of water. It is true that when the engine slips much, the results obtained would be inaccurate and unfair to the engine; but in the second run with the Hidalgo, to which we have referred, no slipping took place, and it would not have been difficult with a little management to get the consumption of water on the run.

The Yorkshire Engine Company have now in hand a very large number of Fairlie engines for diff.rent foreign railways. We do not intend to plunge deeply into a discussion which raged fiercely enough some years since as to the merits and demerits of the Fairlie system, but there are some questions connected with these engines which are very interesting, and should not be passed over in silence. We have stated the Fairlie type of engine is essentially a heavy type, and for this reason: The power of an engine resides in the boiler; and no matter what cylinder power we provide, unless the boiler is able to make steam the cylinder capacity is useless. Now, as compared with other types of locomotive, the Fairlie engine is essentially heavy as regards its gross weight per square foot of heating surface. We do not say that other locomotives are not as heavy; but in the case of the double boiler double bogie engine it is apparently impossible to get a small coefficient of weight per square foot of heating surface, whereas in the case of other types of engine the matter lies almost exclusively in the hands of the designer. The Hidalgo has 1729 square feet of heating surface, and weighs full sixty-two tons. If we deduct twelve tons for water and tanks, we have left fifty tons, or, say, 34.5 square feet of heating surface per ton. But the Iron Duke type of broad gauge engine weighed thirty-eight tons, and had 2000 square feet of surface, or fifty-two square feet per ton; and there is not, so far as we are aware, any reason to think that the heating surface in the one engine is more efficient than in the other. Unfortunately no one seems to know exactly how much heating surface an engine ought to have. There are, however, certain well-recognized proportions, rather undefinable, it is true, but still useful as a

guide, and these proportions are certainly not adhered to by Mr. Fairlie. Thus, it will be seen that the Hidalgo is really the equivalent of two tank engines weighing thirty-one tons each, and having 17 in. cylinders, 20in. stroke. This is rather an unusual proportion, and we may put them as 15½in. cylinders, 24in. stroke. This, however, is a smaller cylinder than will be usually found in tank engines weighing thirty-one tons. Passing this by, it will be found that in practice a tank engine such as we speak of would have about 1000 square feet of heating surface and fourteen square feet of grate. Half the Hidalgo, however, contains only 14½ square feet of grate, and 864½ square feet of heating surface. We do not assert that this is not enough, but we do assert that if it is, we in ordinary practice provide too much; and it would be wise to increase the distance between our tubes, and to use fewer of them.

Another point suggested by the performance of the Hidalgo is the advisability or not of using locomotives of excessive power. We know little of the nature of the traffic the Hidalgo is to work, or of the road she has to traverse, except that she has to get over inclines of one in twenty-five. The question to be solved is simply whether two thirty-ton engines, say on the Fairlie system, would not do the work better than one sixty-ton engine. There must be some limit beyond which it is not advisable to extend the power of a locomotive. What this limit is has never been defined, nor can we find that it has ever been properly discussed. On crowded lines it is obvious that it may be of the last importance to haul very large trains; but on lines of but little traffic, such as exist in general in new countries, it appears to us that in many instances it would be advisable to run two trains instead of one, using a locomotive of half the weight and power required when large trains are adopted. What are the conditions under which one system is better than the other? The point is well worth consideration, and we shall probably return to it.

WATER SUPPLY OF ANCIENT CITIES.

By Lieut. McHARDY.

From the Papers of the Royal Engineers.

In ancient times the water was always allowed to flow of its own accord from a high source to the reservoir, along a channel prepared for it called an aqueduct.

Aqueducts existed at a very early date indeed. Among the first mentioned was one erected by Solomon, to convey water from Bethlehem to Jreusalem. It was similar in construction to much more recent works, the conduit being three feet square, and built of freestone, strongly cemented, and coated one inch thick with plaster. The stones were 15 inches thick.

But the system of aqueducts never reached such perfection as it was carried to in Rome. There vast sums of money were expended on these great public works, and their ruins show that they had been executed in a style of corresponding magnificence.

The first Roman aqueduct was constructed about the year 442 B. C. by the Censor Appius Claudius, whose name it bore. Its total length was about 12 miles.

Another was commenced 40 years after this, which brought the waters of the river Anio to Rome, and the expense of the work was defrayed from the spoils taken in the war with Pyrrhus.

Thus, then, were aqueducts from time to time constructed until, in the time of Nerva, A. D. 96, their number had increased to nine, and before the seat of government was removed from Rome to Constantinople there were about 20 altogether.

The management of these works was intrusted to a public officer, and the position he held was considered very important indeed, the office of *Præfectus Aquarum* was only bestowed on those of the highest rank, who had served the State well, and distinguished themselves in war.

As the principle observed in the design of the aqueducts were the same for all, it may be well to consider for a short time the mode of their construction.

From the inlet at the source until the water was delivered in Rome, the stream

was conducted along a closed channel or specus, having a regular and uniform slope or fall toward the city.

The inclination given by the Romans varied from $\frac{1}{200}$ (Vit.) to $\frac{1}{480}$, being much greater than that generally allowed at the present time; but this may have been necessary for the better scouring of the specus and for preventing any deposit of mud or silt.

In order to maintain the channel at the proper levels it had sometimes to be raised on an earthern embankment, or carried on a series of arches, and sometimes sunk underground and tunnelled through rock.

Embankment was employed when the culvert was slightly above the level of the ground, but when valleys had to be crossed the channel ran on the top of lines of arches. When the level was very much above that of the ground, a second or third tier of arches was built on the lowest series, and the specus laid on top of all.

Our notions of Roman waterworks are apt to be exclusively associated with these gigantic erections, but they supported only a small portion of the total length of the specus. Thus, we find that in the time of Frontinus, A. D. 96, the total length of all the aqueducts was about 278 miles, and of these 28 only were supported on arches. By far the largest part of the channels was below the surface of the ground, for of the 278 miles we find that 243 were underground work.

However, the vastness of the conception, and the great energy in execution displayed in the construction of these lines of arches, give them deservedly a prominent place in our consideration of the Roman aqueducts.

The specus were generally made with rectangular section, or with three sides of a rectangle and an arched roof.

They varied in size from 4 feet high by 2 feet wide, to six feet high by 4 feet 3 inches wide.

It will be allowed that this section for an aqueduct is not well suited for keeping the channel clear of deposit, but the great velocity at which the water must have flowed would have tended to counteract this.

The specus were built of stone or brick, except when they were tunnelled through rock, in which case a brick lining was considered unnecessary. In order to make the culvert water-tight it was coated carefully on the inside with plaster laid on in separate layers. The tunnelled parts of the line seem to have been coated with plaster equally with the parts having the brick lining. The plaster which Pliny declares was found to be the best, was composed of fresh lime slaked with wine, and rubbed with hogs lard and the juice of figs. This was rather a strange composition for a plaster; never likely to be used in this country. However I have made a little of it for an experiment, and find that the plaster is very much inferior, on the whole, to cements made now on a far cheaper plan; but the surface becomes very hard and resists water well.

It is natural to suppose that a large quantity of air would be drawn into these channels by the flow of the water; so, to prevent any serious consequences from the air thus becoming accumulated and compressed in the specus, holes were made which communicated with the open air, and presented a ready escape for the compressed air in the interior. These openings were placed about 130 feet apart along the aqueduct.

When the water had been brought to within about seven miles of Rome, it flowed into a settling pond or piscina. The piscina consisted of a large covered space in which the water might spread out; and thus, having lost its velocity, the mud in suspension would be deposited, and the clear water would enter the continuation of the specus on the other side. The covering consisted of a series of arches, forming long vaults, transverse to the line of the aqueduct. The passages for water from vault to vault, were so arranged as to be in echellon, so that the water was checked as much as possible in its passage through the piscina. In some piscinæ the water passed through four vaults, which were so arranged that two were on a level with the specus, and contiguous, while the other two were immediately under the first two. The water flowed from one on the top into that below it, and from this passed into the other low vault, rising out of it into the one above, when it again entered the specus.

The works were all coated with cement, which remains in many cases intact at the present day.

When the aqueducts approached the gates of Rome great care seems to have been bestowed on the decorative building of the arches, especially when crossing any of the main roads.

The specus delivered the water at last into a castellum, or service reservoir, from

which proceeded pipes to the public baths, private houses, or public fountains through the town. Some of the pipes emitted water on the spot to those who chose to come for it, and were in fact large public fountains.

The name of the castellum may have been given to these reservoirs from the fact that several similar buildings were erected along the course of the aqueduct, in which resided the soldiers who had to guard the works, and the masons who kept them in repair.

The bulk of the people of Rome carried the water from the public fountains, while the higher class had service pipes laid from the castellum to their own cisterns. The quantity of water allowed was regulated by an officer at the castellum, who by means of cocks could stop the supply at pleasure. The pipes in which the water was distributed through the town were made of lead or earthenware. The leaden pipes had a section somewhat oval and pointed on the top. They were not soldered, but simply pressed together, and it is just possible that the old Romans knew that two clear surfaces of lead when pressed firmly together, unite securely and form a perfect joint.

They certainly had the same dread of the solvent action of soft water on lead which exists at the present day. Vitruvius recommended earthenware pipes on this very ground, because "water conducted through earthern pipes is more wholesome than through lead; indeed" he says, "that conveyed through lead must be injurious to the human system." Their earthenware pipes had generally a diameter of about two inches and were tongued into one another in the manner shown in the sketch. In order to strengthen the joints, which were sometimes subjected to a pressure of 200 feet, and therefore were liable to give way, the Romans enclosed them in an envelope of mortar, made with pounded brick, which set so firmly as to make the joints the strongest parts of the pipe.

One other point let us notice—that the Romans never brought the water to the light until it was to be used; and on this account they must have had it free from animal and vegetable impurities, which so readily appear in water exposed to the sun's rays.

REPORTS OF ENGINEERS' SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—The Committee to whom was referred the communications of Professor Estavan A. Fuertes, asking the "Societies to declare what should be the course of instruction in schools and colleges for students of engineering" respectfully presents the following report:

While the Committee fully appreciates the importance of the subject, yet we are of the opinion that the Society is not an advisory body in such matters. Even in regard to professional subjects it guards itself by declaring "that the Society is not responsible for the opinions expressed by its members," and much less would society action on matters pertaining to institutions of learning be considered binding or even advisory. The nearest practical approach to such a position would be the securing of a discussion upon the subject, in which each member would be free to express his opinion, and leave the educator free to draw inferences therefrom.

It is impossible for any body of men to outline a course of instruction which would generally be considered "best," independently of the circumstance which induced them to establish it; and as the circumstances are constantly changing, so courses of study change, in order to be considered "up to the times." In our opinion, the institutions of learning should be left free to construct their courses, and no attempt should be made to mould these after a fixed pattern. The differences which exist between them will then be put to a practical test, and, as they will naturally watch the progress of each other, as well as profit by the criticisms of men in active life, we think that this will in the end lead to the best practical results.

Should this report end at this point, some might infer that we are indifferent to the subject of technical education, and are willing to commit the Society to such a position. On the contrary, we are decided supporters of it, and think that the Society must be, since, on defining the qualifications for membership, it declares "a diploma from any collegiate institution in good standing conferring the degree of C. E. shall be considered equivalent to two years service."

Without disparaging the functions of this Society, it is our opinion that schools of engineering have done more to elevate the standard of the engineering profession than any other single agency. All that pertains to theory and all the classified, practical sciences can and should be taught in the schools. There will always be a practical difficulty in determining the extent to which the details of construction should be taught. It is evidently absurd for the schools to attempt to make experts in any branch of the profession; but this is not a sufficient reason for not teaching, so far as possible, all the *principles* which pertain to practical operations; such as field-work, shop practice, office-work, &c.

The subjects which are intended more especially to promote "board culture" as popularly understood, are not necessary parts of a professional course; they naturally precede technical courses. The system of technical education in this country—if it can be called a system—has peculiarities which have grown out of the circumstances surrounding it. Nearly all the technical schools here devote one or two years to general science and literature—which are no more technical than the old and more purely classical courses. These years are properly preparatory to those which follow. Had we a general system of education, as thoroughly graded as that in Germany, the technical schools would not necessarily

be burdened with this preparatory work; but all things considered, we doubt not but that more thorough work has been done by the system which generally prevails here than would have been by confining the instruction to professional subjects. We ought not to import a foreign system, but seek to build one here especially adapted to our times and circumstances. Our schools ought not to graduate men with a mere "smattering" of the sciences they are to use, but the instruction should be thorough and the standard of graduation high. If an error is made in either direction, the schools should be *too* theoretical rather than *too* practical. The former gives a solid basis upon which to build the professional structure.

It makes but little difference what degree is conferred at graduation; but if that of "Bachelor of Engineering" instead of "Civil Engineer" on the ground that the latter implies a certain amount of practical experience, then we respectfully submit that the latter should be conferred only by a body of practical engineers; such for instance as this Society. In the sense, however, that the candidate has acquired a thorough knowledge of the "Science of Engineering," we see no impropriety in conferring the latter at graduation. The student can become a "Master of Engineering" only by long and varied experience.

Those who desire information upon this subject are referred to the following works.

Report upon Technical Education to the Institution of Engineers, England, made by a committee of that body. London, 1870.

Report of the U. S Commissioner, J. W. Hoyt, on Education in Europe and America. Washington, 1870.

Report of the Committee of the Trustees of the Rensselaer Polytechnic Institute. Troy, 1870.

Respectfully submitted.

DE VOLSON WOOD,
Chairman.

AMERICAN INSTITUTE OF MINING ENGINEERS. FOURTH ANNUAL MEETING, ST. LOUIS, May 27, 1874.

The papers read at the four sessions are enumerated below.

1. On a Safety Plummet Lamp. By E. B. Coxe.
2. On the Pancake Coal of Nevada. By A. J. Brown.
3. On the Occurrence of Antimony in Arkansas. By Prof. C. P. Williams.
4. On a New Coal-Cutting Machine. By J. S. Alexander.
5. Hydro-Geology. By Prof. P. Frazer, Jr.
6. Experiments with Iron and Steel Rails. By Prof. T. Egleston.
7. Occurrence of Lead Ores in Missouri. By J. R. Gage.
8. On the Volumetric Estimation of Zinc by Metallic Silver. By A. Steitz.
9. On the Condition of Carbon in White and Gray Iron. By Dr. Thomas M. Drown.
10. A New Barometer for Measurements of Altitudes. By Prof. P. Frazer. Jr.
11. On the Mechanical Preparation of Anthracite. By R. P. Rothwell.
12. On Rock Drilling. By E. G. Spilsbury.
13. Wastes at American Smelting Works. By A. Eilers.
14. On the Mechanical Analysis of Rocks. By Prof. T. Egleston.
15. Some Experiments in Coking Coals under Pressure. By Prof. E. T. Cox.
16. Arkansas Semi-Anthracite Coal. By Prof. W. B. Potter.
17. The Zinc Process at Carondelet. By John W. Pack.
18. Deep Boring with the Diamond Drill—Supplementary Paper. By Oswald J. Heinrich.
19. Method of taking the Horizontal Section of a Blast Furnace. By F. Firmstone.

SOCIETY OF ENGINEERS OF CALIFORNIA. The above society has held its first ordinary meeting at the Third District Court Room, Mechanics' Institute, San Francisco, when the following interesting papers were read:—"On Boiler Pressure," and "On the Calculation of Earthwork." The following papers were announced as being in preparation:—"On Compound Engines," "On Quartz Mining Machinery," "On the Mechanical Condensation of Vapors, and "On Sea Diving. Mr. J. E. Smedburg, of the Gas Office, San Francisco, is the secretary.

IRON AND STEEL NOTES.

ALLOYS OF IRON.—A new process for the manufacture of alloys of iron with manganese, tungsten, titanium, or with silicon, has recently been brought forward by La Compagnie des fonderies et forges de Terre-Noir, La Voulte et Bességes, which will be found described, with drawings of the special blast furnace used, in the Chronique de l'Industrie, 1873, vol. II., p. 235.

This system consists in mixing cast or wrought iron or steel previously brought to a fine state of division, such as filings, turnings, pulverized iron sponge or granulated iron with ores of manganese, tungsten, or titanium separately or together, or with quartz also, in a state of fine division, and in such proportion as will furnish the desired alloy. When this mixture is moistened throughout with an ammoniacal solution, or with slightly acid water, and compressed into balls by the hand or in an iron mould, heat is developed, and after some hours when the mould is opened, it will be found to have aggregated to a compact and hard mass requiring blows of a hammer to break it into fragments, which will stand a red heat and not begin to break up until almost at their point of fusion. By treating these blocks or fragments in a suitable furnace at a very high temperature, alloys of iron, containing from 25 up to 75 per cent. manganese, silicides of iron, containing up to 22 per cent. silicon or alloys of iron with tungsten and titanium, or triple alloys of these different metals, may be obtained. The furnace employed is a small cupola, the shaft of which is made of the best of firebricks, and rest upon a cast-iron bearing ring, supported by four pillars, so that the whole of the lower part of the furnace may be removed when required for repairs; between the lowest part of the shaft, which is conical, and the crucible or hearth of fusion, is an intermediate part, also conical, recommended to be made of lime, magnesia or pure alumina, encased in a sheet iron conical casing, supported or hung from the bearing ring previously alluded to, and

below this the movable crucible, which is simply pressed or held up to meet the conical part by means of wedges below it, so as to be easily disconnected for repairs, as it is very strongly attacked during the operation. The crucible itself is formed of lime magnesia, or also of a solid piece of carbon, made by mixing powdered graphite, gas coke or other pure coke, with tar, and then baking the whole at a low red heat for some hours until it forms a compact hard mass, free from cracks or fissures. At the top of the crucible, a single tuyere lets in the blast, which should be heated at least to 670° Fahrenheit, and have a pressure of some 5 or 6 inches of mercury. A patent, No. 1,574, dated May 1, 1873, by A. Browne, London, being a communication entitled "Furnace for the Manufacture of Metallic Alloys," appears to embody all the features of the above process.

As a substitute for and as an improvement upon cast steel, M. Levallois, of Paris, has patented in France the employment of three new alloys of iron, with tungsten and nickel, which can be worked like ordinary steel, and are said to be very hard. The three alloys contain the respective metals in the following percentage proportions:—No. 1, soft iron 93 parts, tungsten 6½ parts, and nickel ½ part: No. 2, soft iron 95 parts, tungsten 4½ parts, and nickel ½ part; and No 8, soft iron 97 parts, tungsten 2½ parts, and nickel ½ part. The crucibles and furnaces employed are similar to those ordinarily used in melting cast steel, but a special flux is made use of, which is composed of 36 parts boracic acid, 32 parts calcined quartz, and 32 parts washed carbonate of lime; all of these substances, after having been powdered and mixed, being melted together in a crucible, poured out upon an iron plate, and the solidified mass broken into small fragments. When making the alloy, the tungsten and nickel are first placed in a tube of soft iron, with about 1 per cent. of the flux, and this tube is placed in the middle of the rest of the iron in the crucible, which is itself covered with from one-half to 2 per cent. of the same flux. When the whole is melted it is poured as usual into moulds of sand or metal.—Chronique de l'Industrie, vol. 2, p. 170, 1873.—*Journal of the Iron and Steel Institute.*

DEFINITION OF THE TERM STEEL.—In the Memorial du XXV Anniversaire of the Association of Engineers of the School of Arts, Manufactures, and Mines of Liége, published this autum at Liège, M. Adolphe Gruner, the head of the steel department of the Société John Cockerill, at Seraing, communicates a note on the "Definition of Steel." This gentleman had previously, in 1869, defined the term steel as including all malleable products of iron industry, obtained from a state of fusion, in contradistinction to the term iron, which he reserved for all malleable products which have not undergone absolute fusion; although this definition has been accepted by Professor Jordan, and other writers on siderurgy, it clashes somewhat with our old views, to find that under this sytem, our long-known cementation, or blister steel, must be regarded but as carbureted iron, while fused iron, containing none, or but a trace of carbon, must be classified as steel. The two series of products, i. e., the irons and steels, are classified by M. Gruner as follows:—

Percentage of Carbon.			
0 to 0.15p.c.	0.15 to 45p.c.	0.45 to 0.55 p.c.	0.55 to 1.50p.c. or more.
Series of Irons.			
Ordinary Irons.	Granula Irons	Steely Irons or Puddled Steels.	Cemented Steels. Styrian Steels.
Series of the Steels.			
Extra soft Steels.	Soft Steels	Half soft Steels.	Hard Steels.

RAILWAY NOTES.

LIGHT AND ECONOMIC TRAMWAYS.—Reference was made in the *Mining Journal* of April 25 to an improved method of transport without breaking bulk on mixed-gauge railways, invented by Mr. JOHN WALKER, of James street, Old street, and the patents having now been completed some further details of the invention can be given. The first object of the invention is to make the top surface of the rail as low as possible to the ballast, to prevent the wheels from jarring the sleepers or bottom frame of the railway. To accomplish this each sleeper is notched out by four circular saws from 2in. to 3in. deep, and to the exact gauge required for the railway. These notches or grooves cut across the sleepers are to receive the rails, and may be so made as to fit down tight, or have space for a wedge on the outside. The rail is formed of one piece of timber in the centre, and an iron plate on each side, and is called the composite rail. The timber may be 3¼in. deep by 1¼ in. thick, and the two plates of iron 3¼in. deep by ¼in. or 3-16 in. thick; these plates are either rivetted or screwed together on the timber, taking care that no joint of iron or timber rests upon the same sleeper. In this way we have a continuous rail with out a but joint, which not only makes a strong rail but also the most pleasant to travel on, having just enough elasticity to secure that purpose. By placing the rails into the sleeper instead of on the top, they form in themselves a complete frame independent of spikes or screws to whatever length they may be carried, and as each sleeper is exactly alike, the rails will also be perfectly true, so that the wheels of the engine may fit exactly, instead of oscillating from side to side, doing more damage to the rails than the weight of the engine.

For general traffic the head of the rail is formed either of angle-iron or a steel cap, bolted through the rail with bolts and nuts, care being taken that the joint is not over any other joints of the rail; in this way when the cap wears out it is easily renewed without disturbing the framework of the rails, and at a very small cost, and great saving in labor and materials, thus rendering this invention of the greatest importance for branch lines, and also wherever railways are required to open up new countries, when the cost would, it is estimated, amount to about one-half that of the present system. From a series of carefully conducted experiments made by Mr. David Kirkaldy, it appears that taking the centre between the sleepers, a rail 3¼in. deep is equal to 9 tons; 4¼ in. deep, 14 tons and 5 in. deep 18 tons. There would, of course, be a great saving of freight when exported, and in laying down a line in the cost of labor and time, there being no chairs, fish-plates, trenails, &c., required. For the construction of light and cheap lines for bringing down ore, &c., from mines in sparsely populated districts the system appears well worthy of attention.

RUSSIAN RAILWAYS.—The combined receipt of all the Russian lines amounted in December

to 11,914, 829 roubles, against 8,601,863 roubles in December, 1872, showing an increase in the closing month of 1873 of 38½ per cent. The aggregate receipts of all the Russian lines in 1873 were 122,877,263 roubles, as compared with 101,-973,836 roubles in 1867. The average receipts per verst worked presented an increase in 1873 as compared with 1872, of 10.80 per cent. Nearly one-third of the traffic comprised in last year's revenue passed over the Great Russian Railway.

ENGINEERING STRUCTURES.

THE MERSEY TUNNEL.—We have from time to time referred to the project for constructing a tunnel under the Mersey at Liverpool, which owing to the navigation of the river, is the only possible way to connect the Lancashire and Cheshire shores.

Some time ago a shaft was sunk on the Birkenhead side of the Mersey, in order to ascertain the nature of the rock, and the borings have been driven for a distance of about 250 yards westward of the river. The result of this examination was of the most satisfactory character. The stone was found to lie in horizontal strata, and to be of the most homogeneous character, and without flaws through which the water might penetrate; but, in order to render the tunnel perfectly dry, it will be lined with brick and cement. The *Liverpool Mercury* says the sinking of the shaft on the Liverpool side will be commenced almost immediately, and those who understand the nature of the contemplated works believe that they will be carried out without any difficulty. The works have been jointly planned by Mr. John Fowler, C. E., and Mr. James Brunlees, C. E., and they are under the immediate superintendence of Mr. William Morton as resident engineer.

Parliamentary powers for the formation of this tunnel have already been obtained, but there has been a departure from the original scheme, and a new company has been formed, not only for the carrying out of the work, but for certain important contemplated extensions of the line on the Liverpool side of the river. According to the original scheme, it was intended to carry the Liverpool end of the tunnel into a capacious station to be erected near Compton House, and also to unite the railway with the service of the Cheshire Lines Committee in Ranelagh street. This, however, has for the present been abandoned; and according to the amended plans, the tunnel, when completed, will terminate at a central passenger station which it is proposed to erect near Hatton Garden, between Victoria Street and Crosshall Street. From this station a line for goods' traffic will curve towards the west beneath Vauxhall Road, and down towards the Waterloo Road and the Prince's Half-tide-Dock, emerging from the tunnel on a level with the dock railway, which will be connected with a large goods' station to be erected between Great Howard Street and the Waterloo Road.

The new station to be constructed near Hatton Garden will be 25 feet below the surface; but arrangements will be made for an approach from the street for cabs, so that the necessity for lifts, such as were once contemplated, will be entirely obviated. Descending by a gradual incline from Dale street, the tunnel proper under the Mersey will be reached—or rather it should be said the two tunnels, for the up and down lines will be in separate excavations, each cut out of the red sandstone rock, with a pier or support of solid rock, 15 feet in thickness between them. The length of the submarine portion of the tunnel, from shaft to shaft, will be about 1,200 yards, the breadth 25 feet; and the height, from the rail level to the underneath surface of the arch, will be 17 feet; the whole lying about 25 feet below the bed of the river. On emerging from the tunnel at Birkenhead the line will be so constructed as to form a junction with the Great Western Railway not far from Green Lane. It is believed that as soon as the works referred to are carried out the Cheshire Lines Company will seek a revival of their powers, and obtain authority to effect a junction by a line, chiefly underground, with the new station in Dale street, starting near St. Andrew's Church, thence beneath Great Charlotte street and St. John's Market to Dale street. When these works are carried out, the Midland, the Great Northern, the Sheffield and Lincolnshire, and the Great Western Railway, with its network of lines, will be in union, thus opening direct communication between some of the most important districts of the kingdom. Under no circumstances can the tunnel be formed in less than three years; and should unexpected engineering difficulties arise the task will occupy even a much longer period. —*Architect*.

THE CHENAB RIVER BRIDGE is in progress of construction at the establishment of Messrs. Westwood & Baillie. This structure is intended to carry one of the Indian state railways across the river Chenab in the Punjab; it has an aggregate length of over 1½ miles, and is composed of sixty-four spans of 142 feet in length, each measuring from centre to centre of the intervening piers. Each girder, or rather each pair of corresponding girders constituting a span, is independent and discontinuous, so that any vibration or oscillation communicated by the passage of a rolling load over any one span is confined for the time being solely to that span, and produces no effect upon the remaining spans in the structure. Each girder has a depth of 9.174 feet, measured from centre to centre of the vertical plates in the upper and lower flanges respectively, and the total depth from out to out is 1 foot more. The flanges are of the ordinary trough shape, built up of vertical plates, one series of horizontal plates, and connecting angle irons. These last we noticed are single, that is riveted to only the outside of the vertical plates at their junction with the horizontal ones. This is similar to the arrangement adhered to in the flanges of the Charing Cross bridge. It does not form by any means so good and advantageous an attachment as is effected by the use of double angle irons riveted to the vertical plates on both sides. The variation in the sectional area of the flanges is made partly by decreasing the depth of the vertical plates and partly by differences in the number and thicknesses of the horizontal plates. An important point to be kept in view with regard to the employment of deep vertical plates in the flanges of girders is that they directly tend to reduce one of the most important elements of strength in the depth.

The Chenab girders are of the Warren type, and are built with a camber. The web consists of

one series of triangles, the bars of which are inclined at an angle of 60 deg. with the horizontal. A pair of diagonals meeting at each apex, are connected to the flanges at intervals of about every ten feet. Each diagonal is composed of four angle irons with cross bracing between each pair, in the place of the cross section of the girder. No pins are used, as might be expected from the character of the design, but all the connections are formed by rivets. Strong gusset plates are riveted at the intersections of the diagonal bars of the flanges. These are absolutely necessary in order to provide against the great local strain arising from the concentration of the weights at those points. The cross girders are placed about five feet apart, one at each side of the lower apices of the equilateral triangles of the web, and the platform of the bridge is formed of buckled plates made on the premises, and riveted to the cross girders. There are no rail-bearers, as the metals rest close down upon the platform. The bridge has a single line of rails, and is intended also for the passage of ordinary wheeled vehicles, cattle and foot-passengers. At certain intervals some of the spaces are widened so as to serve as a refuge while trains are passing. It was suggested by one of the visitors, not so incongruously as might at first sight appear, that the lower flange of the main girders would answer exceedingly well as a drinking trough for cattle. The workmanship of the bridge, which was well shown in a pair of girders erected on the ground, constituting a complete span with cross girders and platform, gave great satisfaction to the visitors, nearly all of whom were competent judges of such matters.

In addition to the Chenab girders, and among others of a smaller description, Messrs. Westwood & Baillie have in hand some for one of the Government railways in Japan, a country which certainly does not intend to be behind the age with respect to steam communication inland. There appears to be a large amount of unnecessary cutting, bending, and forging in the iron work for these structures. The designer seems to have lost the principle that the nearer any particular section of iron can be kept to the form in which it leaves the rolls the cheaper the workmanship can be done, especially if the iron be in long lengths.

NAVAL AND ORDNANCE.

THE REFFYE FIELD GUN.—One of the most interesting pieces of field artillery in the Vienna Exhibition was the bronze breech-loader invented by Lieutenant-Colonel Reffye, of the French artillery, and mounted for view near the Machinery Hall entrance to the Rotunda.

Already, before the late Franco-Prussian war, the defects of the service field artillery were recognized by the French Government, and experiments on new guns were instituted with the ultimate view of selecting an improved weapon. The only gun which was even partially tried before the war broke out was the Reffye "cannon de 7," which was made at Meudon and experimented on at Versailles in the month of June, 1870.

At the capitulations of Metz and Sedan, the French army lost the greater part of its artillery, and the task of supplying their raw levies with a new weapon which should cope with the Prussian field guns devolved upon the Government of the National Defence. Their choice fell upon the Reffye breech-loader, and before the close of the war over 2,000 of these weapons were manufactured, which rendered good service during the Prussian siege of Paris and the rebellion of the Communists which followed after.

In the beginning of 1873, a series of experiments on guns of this system was carried out at Calais with very satisfactory results. Since then the "cannon de 7" has been adopted definitely as the principal arm of the French field artillery. The gun is made wholly of bronze, its general shape being cylindrical from the breech as far as the trunnion ring, and conical from thence to the swelling at the muzzle.

Its principal dimensions are as follows:

Calibre	85 millimetres...	3.5 inches.
Diameter of powder chamber...		3.642 "
Total length ...	2.01 metres.....	79 214 "
Length of bore ...	1.875 "	73.8 "
Weight of gun ...	640 kilos.....	12.6 cwt.

The bore is rifled with fourteen grooves, having a depth of 1.5 millimetres, and a uniform twist of 5° 44′. The breech-closing arrangement consists of the screw with portions of the thread removed which has been already described in Engineering. When the screw is withdrawn from the breech it rests in a steel ring, let into the end of the gun, and mounted on hinges like a door, so that it can be swung back, thus leaving the passage to the chamber free. The touch-hole is drilled obliquely through the screw in such a position that if the latter be not securely driven home, the mouth of the touch-hole lies hid behind a covering plate fastened to the steel ring, and the charge cannot be ignited. Accidents are thus rendered impossible.

The cartridge case is very remarkable, serving as it does not only to inclose the powder charge, but also to prevent the escape of gas through the breech-screw and touch-hole. It moreover prevents the powder chamber from becoming unduly heated. With these ends in view, the case is made up of three distinct parts, namely:

1. A cup-shaped base of sheet brass, which when the explosion takes place is expanded like a Bramah collar, so as to close completely the touch-hole, and also the lines of contact between the breech-screw and the base of the powder chamber.

2. A cylindrical body of tin-plate, which is covered within by four coils, and without by three coils of paper.

3. A cylinder of strong pasteboard which unites together the cup and the body.

The two last-named parts not only strengthen the cartridge-case, but act also as non-conductors which prevent the chambers from becoming heated, and moreover save it from the erosion due to the action of the powder gases.

The cartridge-case is extracted after each round by a very simple contrivance. The head of the breech-screw is hollowed out so as to form a shallow truncated cone, and in the side of the cone three spiral scores are cut. When the explosion takes place, the cup-shaped base of the cartridge is blown into this hollow cone, and the soft brass is imprinted into the scores so firmly that on the screw being turned round and withdrawn it carries with it the whole case. It would seem at first sight that the metallic body of the

cartridge would expand so tightly against the sides of the chamber as to render the withdrawal impossible. This difficulty, however, is prevented by leaving the seam in the metal cylinder unsoldered, and covering it simply by a metal strip, which of course allows the cylinder to spring without becoming permanently expanded, while the strip, together with the pasteboard and cartridge paper, maintain the case gas-tight.

The ordinary charge consists of five rings of cake powder, formed by compressing common gunpowder till the specific gravity is 1.615. The rings have an internal diameter of 52 millimetres, and are placed one above the other, so as to form a hollow cylinder, the weight of which is 1.130 kilogrammes. The head of the cartridge is occupied by a disc of grease inclosed in a pasteboard cup.

The projectile is a common scored cast-iron shell weighing 6.9 kilogrammes = 15.2 lb., the length being three times the calibre. Originally it was enveloped with a continuous lead jacket to take the rifling. This has now been done away with and two leaden rings substituted. Experiments on the projectile seem, however, still to be pending, and till these are completed it would be useless to go into the matter further.

The Reffye gun has recently been subjected to an exhaustive series of experiments at Calais by a commission of French artillery officers, the results of which have been chronicled in the "Revue d' Artillerie' by the Chef d' Escadron Mercier, one of the members of the commission.

The following are some of the results as regards range, elevation and time of flight, the charge and the projectile being the same as those given above and the initial velocity being 390.3 metres.

Time of Flight.	Angle of Descent.		Angle of Elevation.		Range.
secs	deg.	min.	deg.	min.	
0·53	0	25	0	12	200
1.12	0	56	0	38	400
1.66	1	31	1	7	600
2.28	2	9	1	39	800
2.91	2	51	2	12	1000
3.95	3	34	2	47	1200
4.27	4	19	3	24	1400
4.95	5	5	4	2	1600
5.68	5	53	4	41	1800
6.43	6	41	5	21	2000
7.19	7	33	6	2	2200
8.00	8	26	6	45	2400
8.82	9	21	7	29	2600
9.66	10	16	8	14	2800
10.54	11	20	9	0	3000
11.45	12	27	9	48	3200
12.36	13	40	10	38	3400
13.37	15	0	11	30	3600
14.37	16	29	12	25	3800
15.38	18	8	13	23	4000
16.49	19	58	14	25	4200
17.61	22	3	15	31	4400
18.80	24	23	16	43	4600
20.08	26	59	18	1	4800
21.43	29	51	19	27	5000
22.88	33	5	21	3	5200
24.47	36	40	22	51	5400
26.40	40	35	24	55	5600
28.39	45	1	27	26	5800
30.62	49	5	30	28	6000

These results were considered eminently satisfactory, and as regards accuracy in shooting, the weapon leaves little to be desired.

The breech-loading apparatus, which is tolerably free from complication, worked fairly in the trials, but it is far inferior to the Broadwell cylindro-prismatic wedge.

The metallic cartridge-cases merit favorable mention. As an instance of the value of the latter in saving the chamber from deterioration, it may be mentioned that after a sustained fire, first of 115 and then of 240 rounds, although the muzzle became extremely hot, the breech never exceeded a very moderate temperature, and could always be touched by the hand without the slightest discomfort. Upon the whole, the French Government and Colonel Reffye must be congratulated on having produced results which have never before been attained with any bronze field gun.

WHITWORTH ORDNANCE.—The Committee on Artillery Studies, after nearly two years of consideration of the various system of cannon, have pronounced definitely in favor of the Whitworth rifle cannon as that which, from its material, the processes of manufacture, and the system, most nearly approaches perfection. The committee emphatically condemn the French system of cast-iron strengthened by wrought-iron bands, as unscientific and practically proved inefficient. The Krupp gun, of Krupp cast steel, strengthened with bands, they consider unreliable, notwithstanding its fine material, chiefly owing to the uncertainty and irregularity of effect which, they say, always attend the action of the hammer, however ponderous, on masses of iron. Finally they consider the English Armstrong, Woolwich, and Whitworth cannon much superior, in construction and strength, to the best yet produced on the Continent, the Woolwich an improvement on the Armstrong, and the Whitworth far ahead of either in the essential qualities of a good gun. This superiority of the Whitworth cannon the committee ascribe to the quality of the homogeneous steel used, to the care in its selection, to the oil tempering which it receives, to the use of the hydraulic press instead of the hammer, and to the mode of constructing and connecting the cylinders and other parts of the gun. In relation to the quality of duration, the committee mention that, while the Krupp cannon has an average life of 600 to 800 shots, the Whitworth cannon employed by the Brazilian forces during the Paraguayan war, have averaged 3,500 to 4,000 shots each, without a single case of bursting or serious damage having occurred among them.—*The Brazilian Times.*

BOOK NOTICES.

SANITARY ARRANGEMENTS FOR DWELLINGS, INTENDED FOR THE USE OF OFFICERS OF HEALTH, ARCHITECTS, BUILDERS, AND HOUSEHOLDERS. By WILLIAM EASSIE, C. E., &c. Smith, Elder & Co. 1874. 12mo, clo., $2.75. For sale by D. Van Nostrand.

This volume gives, in a collected form, a series of papers published originally in the *British Medical Journal*. Its object, the author states, is to give "an account of the most ordinary sanitary defects in dwelling-houses and public institutions, in respect to drainage, water-supply, ventilation,

warming, and lighting;" and "to set forth," what he believes "the most simple and effective means of *preventing* or *remedying* such defects." He thinks it necessary to say further:—"The purpose of this small work is to point out, in the plainest language, what ought to be done to render ancient and modern houses healthy. I will eschew all extraneous matter, as much as possible, and will not fall into the common practice, better honored in the breach than the observance, of heading the chapters, or interlarding the matter with lines from the poets." It is but due to the author to say that he has faithfully avoided this tendency "to drop into poetry" on the subject of house-drains, sewers, &c.; on the plainness of the language, however, we cannot speak very highly. Many householders, it is to be feared, will find some difficuly in recognizing an S-shaped pipe under the name of a "sigmoid"; or in appreciating the beauty of a description in which the overflow sewage from a cesspool is said to "debouch into the fields"

The greater part of the book is occupied with a description of the various sanitary appliances for buildings which have from time to time been proposed, or which have been brought into actual use; such as drain-pipes, of which twenty-two different kinds are figured and described; traps, of which thirty-six are given; fire-grates and stoves, &c. In many places, indeed, it reminds us of nothing so much as a manufacturer's or tradesman's catalogue. On the whole, however, this work contains much useful information and many excellent suggestions. On the subject of house-drainage, we are glad to see that Mr. Eassie has adopted and advocates the principle of leading all house-drains into one collecting drain, outside the house if possible, and placing in this main drain an efficient trap, properly ventilated so as to prevent any of the sewer gases finding their way into the house through the drains or pipes.—*Nature.*

MATERIEL DES CHEMINS DE FER DE FAIBLE TRAFIC ET TRAMWAYS A VAPEUR.—Par AMEDEE SEBILLOT (Paris). This is a pamphlet on rolling stock for small railways and steam tramways, which is now attracting much attention in France. The object, of course, is to produce economy in industrial and other branch lines; or, to put the case in the author's own terms, lines to be executed of which the receipts cannot be estimated at more than 5,000 to 6,000 francs per kilometre that is to say, £320 to £384 per mile. For such lines, whether laid by the side of roads or otherwise, the conditions of the case will generally necessitate inclines of 0.05 to 0.06. Many instances prove that lines of such profile may be worked with carriages of simple adhesion; but in such cases the ratio between the true load and the dead weight is the cause of considerable expense. On inclines of 0.05 a locomotive cannot draw more than its own weight, which brings the ratio of useful load to only twenty-three per cent. of the total weight set in motion. In such cases the author asks whether it is rational to separate the engine from the carriage. He advocates, in fact, steam-carriages, which he has found to give fifty-three to fifty-six per cent. of useful load, that is to say a reduction of total weight to the amount of fifty per cent., and, of course, this produces great economy in first cost, maintenance, and fuel. M Sébillot finds, by calculation, that the cost per kilometre, which is 5,000 fr. by ordinary trains, would be reduced to 3,000 fr. by steam carriages; and he quotes the success of such carriages in the United States. M. Sébillot has calculated the cost of such steam-carriage of three types:—(1) for passengers and small parties only; (2) mixed; and (3) for goods only; the carriages being provided with a lateral as well as an angular movement of the extreme axles, so as to work readily in courses of twenty metres' radius. In these carriages the effective weight contributing to the adhesion, that of the machinery and framing, may be greatly reduced, while the suppression of the coupling chain and buffer-springs, and the consequent absence of shocks, allows of comparatively light construction. The following are the results arrived at with four types of carriage: (1) passenger and parcel carriage for inclines of 0.03—dead weight, 7,000 kilogs.; effective load, 8,000 kilogs; (2) mixed ditto for same inclines—dead weight, 8,800 kilogs.; effective load, 11,200 kilogs.; (3) passenger and parcels carriages, for inclines of 0.05 to 0.06—dead weight, 9,300 kilogs.; effective load, 10,700 kilogs. (4) goods carriages—dead weight, 12,500 kilogs; effective load, 17,500 kilogs. By adopting a very economical mode of construction, M. Sébillot states that such branch lines may be made at 45,000 per kilometre (£2,880 per mile, or at the roadside for 25,000 fr. (£1,600 per mile), so that lines might be constructed which would only earn from 4,250 fr. to 5,500 fr. per kilometre.

ECLIPSES, PAST AND FUTURE, WITH GENERAL HINTS FOR OBSERVING THE HEAVENS. By the Rev. S. J. JOHNSON. Oxford and London: Parker & Co.

This work, which is as well conceived as it is carried out, contains some most interesting notices of ancient eclipses, and also of the most important during each century of the Christian era up to the present time. A peculiar feature of the book is a list of eclipses of the sun and moon from 1874, October 10, to 1912, April 1; and from 1912, April 17, to 2381, July 21, eclipses of the sun only. Although not very interesting to the present generation, these remote eclipses, predicted to occur within the next 500 years, will acquire a progressive value in the opposite direction to that of ancient eclipses, in affording data for the further correction of the lunar and solar tables, for doubtless, as astronomical science advances, residual phenomena may be found which will throw still further light on the motions of the bodies of the solar system. The second part of Mr. Johnson's work, entitled, "A Cycle of Celestial Objects for a Small Telescope," is arranged on the plan of Webb's "Celestial Objects for Common Telescopes," but is by no means an imitation of that useful book. It contains brief notices of such double stars and nebulæ, amounting to 152, which may be studied with telescopes under four inches of aperture, preceded, as in Webb, by remarks on the bodies of the solar system, the aurora, meteors, &c. In the notices of the planets, the author gives the dates in future years when the most interesting phenomena of each planet may be looked for, and thus his work becomes in a measure ephemerides of eclipses, transits, and occulations for many years to come. In his arti-

ole, "The Earth," the author enumerates some of the most striking phenomena in physical geography, seismology (earthquakes), and meteorology, and under that of the "Moon" he points out the most important lunar formations as they successively come into sight. By the way, the only error we have noticed in the work is in connection with the celebrated spot Linne, which the author places in the Mare Tranquillitatis. It is really, as most of our readers are aware, on the Mare Serenitatis. Under the head of "Meteors," the author alludes to Mr. E. L. Garbett's suggestion that the cities of Sodom and Gomorrah were destroyed by the group of meteors following Tempel's comet of 1866.

We most cordially recommend this work to amateurs who may desire to possess a suitable Companion to "Celestial Objects for Common Telescopes."

THE TRUTH ABOUT SEWAGE IN A FEW WORDS. By Andrew Fenwick. London: W. Isbistern & Co., 1874.

In a few lively and short chapters, Mr. Fenwick places this usually opaque matter in a clear light. Setting out with the postulate that the excreta which are the essential parts of town sewage are only valuable for the ammonia they envelop, he reviews the various sewage solutions proposed and the aspects of sanitation as connected with sewage, and in conclusion shows that the question is one of great complexity, so that a prescription successful under one set of circumstances, may be wholly inapplicable in another. "The flood discharged into the Thames at Crossness bears away," he says, "myriads of tons of potential manure; but that manure is irrecoverable by any process that would not exceed its value manifold. Fortunate is London in having such an outfall. Other towns less favored are bound to do something to avert river pollution; but whatever they do it will cost money, and, in some cases, much money."

ELEMENTS of Metallurgy, a practical treatise on the art of Extracting metals from their Ores. By Arthur Phillips. 8vo, cloth, $15.00. For sale by D. Van Nostrand.

This is a new edition of Phillips' Elements of Metallurgy, forming a large octavo volume, of 750 pages, and nearly 200 engravings. No expense has been spared in carrying out the design of the author, viz: the production of a work which shall present to the student in a concise and practical form, the information at present to be gathered from the perusal of several distinct treatises. The text is elucidated with numerous wood-cuts (many of which have been redneed from working drawings) executed under the superintendence of Mr. W. Welch. The general contents of the work embrace a treatise on fuels and refractory meterials. A description of the principal metalliferous minerals with their geographical distribution. Statistics of the amount of each metal annually produced throughout the world, obtained from official sources or authentic private information, and the methods of assaying the different ores, together with the processes of metallurgical treatment.

EARTHWORK MENSURATION, on the Basis of the Prismoidal Formula; Containing a Simple and Labor-saving Method of Obtaining Prismoidal Contents Directly from End Areas. By Conrad R. Howard, C.E. New York: D. Van Nostrand, 23 Murray and 27 Warren Streets. Price, $1.50.

There is probably nothing to which the civil engineer has more frequently to trace annoying errors in his aggregate estimates than to his many trifling mistakes in calculating the amount of earthwork involved in overcoming the many natural obstacles with which he has to deal, and the tedious nature of the processes hitherto adopted for obtaining the desired results has certainly been some excuse for inaccuracy. Recognizing these facts, Major Howard, C. E., of Richmond, Va, U.S., has prepared a very valuable treatise, the object of which is to enable the practical engineer to calculate the true prismoidal contents of a mass of earth to be removed with the same facility as averaging end areas, and that this object has been attained is acknowledged by some of the most eminent engineers who have already ha' the opportunity of testing the book. By the employment of only a couple of dozen pages of tables, the calculation of which has, doubtless. involved a considerable amount of labor, Major Howard is enabled to present a new and systematized method of finding the prismoidal contents of earthwork by the use of rules readily understood, and easy of application by any one accustomed to the ordinary business of an engineer's office, the method possessing, moreover, the great advantage that by giving accurate corrections for the fami iar approximations in general use the calculator has, as the author very truly remarks, the element of error constantly before him, and must speedily learn by practice, if not by theory, the cases in which such corrections become important.

As all works of this class are valuable or worthless, according as they are reliable, or otherwise, the first inquiry which necessarily suggests itself is whether the author is scientifically correct in the principles which he recommends for adoption, and that there may remain no question upon this point, Major Howard devotes the first 20 pages of his book to the strictly mathematical investigation of those principles in such a manner as to show the derivation of the formulæ to be employed in practice; while the second part contains the necessary instructions for obtaining the prismodial contents sought, and supplies practical rules and examples, showing the uses of the tables in simplifying computations by the formulæ given, so that whether it be required to find the prismoidal contents of thorough-cut or fill when the road-bed widths and side slopes are constant between the end sections; of side-hill work. pyramids, &c., with similar end sections; or of thorough-cut or fill when the end road-bed widths are different; and to make the necessary correction for curvature in single width throughout, or in side-hill work when the transverse surface slope is regular, the requisite calculation can be easily and quickly made. It is pointed out that the rules for computation of cubic contents are based on the condition that the transverse service lines of the end sections shall be sensibly similar, but it is very properly pointed out that by combination they will cover all cases to which the method of "roots and squares," and of "equivalent level heights," can be correctly applied, and that the practical limit of their application may be indefinitely extended by increasing

the proximity of the cross sections in rough ground.

With regard to the tables, Major Howard states that he has calculated them himself, and as the system used was that of continued additions with special tests at intervals, he believes they will be found absolutely correct within the purposed limits, whether the last figure of any amount given be intended to express the nearest whole number or the nearest decimal; and, judging from the results obtained with the rules and tables applied to three or four examples taken indiscriminately, with a view to test them, we do not hesitate to say that they are quite reliable. The work will prove of almost inestimable value to practical men from the vast saving of time that will be effected by its use when estimates of as near as may be perfect accuracy are desirable, and for this reason it is likely to find great favor with the engineering profession. —*London Mining Journal.*

MISCELLANEOUS.

THE ARMOR-PLATED "INFLEXIBLE."—The belief of Admiral Elliott that the days of armor-plating are nearly over, is certainly not justified by this extraordinary vessel. The exact drawings and particulars of her build are very naturally kept from public knowledge, but we may, without any breach of patriotism, give a general conception of the design adopted in this, the youngest of our iron clads. What may be called the distinguishing characteristic of the *Inflexible* is that she will have, in the sense of vulnerability, no "wind and water line" at all, Every one must know that the vitals of a man-o'-war lie along the belt of her flotation—a breach of her sides in that region lets in the sea and swamps her. The *Inflexible* carries all her side armor upon a central space 110 ft. in length. It is 24 in. thick, and protects with that monstrous wall of solid iron her engines, her crew, and her battery of four 80-ton guns. Along the rest of her—fore and aft—there is no vertical armor, but a thick inside cushion of cork of enormous buoyancy, more than 60 ft. square in section, surounding bunkers full of coal for the supply of the ship. A horizontal deck of thick metal extending fore and aft from the citadel, at a depth of 6 to 7 ft. from the water line, will cut off all this unarmored upper portion from the real hold of the vessel. Thus if the enemy should send shot or shell through every coal bunker and corner of the *Inflexible*, forward and aft, letting in the water everywhere, he could only—if the design answers expectation—lower her a single foot in the sea. Her citadel, it may be confidently expected, he could not pierce; at any rate with guns at present in use. In a word, the constructors of the *Inflexible* give an enemy the upper slices of the ship, except her citadel, to do as he likes with; and it is by making the ends floatable under any circumstances that the iron work of the ponderous citadel, with its turrets and freeboard, can be carried. The ram and the torpedo are therefore the only perils which threaten this forth-coming fighting ship; but perhaps these also might be provided against if her bottom under the water deck were constructed in many compartments. Enough, however, has been already hinted about our newest behemoth to show that, whatever her success, the age of armor-plating is not ended yet.—*London Telegraph.*

THE BESSEMER SALOON STEAMER.—This vessel, intended to obviate sea-sickness in the passage across the Channel, is rapidly approaching completion. The vessel has become completely plated, and the fitting of her engines and boilers in place will soon be accomplished. This work will be done while the ship is on the stocks, so that when she is launched she may by the same tide be sent upon her trial trip. The vessel, so novel in her construction, is an object of great interest, and scarcely a day passes without several visitors from a distance inspecting her. The ship is 350ft. long at the water-line, and for 48ft. at each end, the deck is only about 4ft. above the line of flotation, so that in rough weather the sea will wash over these low ends. The decks on this portion of the vessel have a considerable curve and the sides of the ship are rounded off so that the water may escape as speedily as possible. This form of end has been selected with a view to obviate any tendency to pitching. Above these low decks a breastwork is erected about 8ft high. It is 254ft. long and all the width of the vessel. The whole of this breastwork deck is to be devoted for the use of the passengers, and that portion fore and aft of the paddle-boxes will be protected with staunchions. The vessel will be propelled by four paddle-wheels, and 90ft. of the space between the paddles will be occupied by the swinging saloon. Beyond this at each end is occupied, nearest the saloon by the engines, and next by the boilers. At one end of the breastwork there will be accommodation for the crew of the ship, and beneath their quarters stowage room for passengers' luggage, &c. At the opposite end of the breastwork the space is fitted with cabins for the special use of ladies, and below these cabins there is a saloon 51ft. long, and fitted with sofa seats all round. Along the sides of the breastwork deck, between the paddle boxes, there are other cabins for passengers beside smoke rooms and refreshment rooms. The Bessemer swinging saloon is making good progress, and already a good idea of the principle may be obtained by an inspection of the work. The saloon proper is about 70ft. long, 26ft. wide, and very lofty. The weight of the saloon is borne by four large bearings, one at each end and two near the centre. The end bearings are fixed on iron transverse bulkheads, which are well stiffened by fore and aft ways to prevent them buckling. The saloon will be one of the most superbly fitted apartments afloat. The top of it will form a promenade deck, and it will be fitted all round with seats. The saloon will be entirely under the control of the machinery invented by Mr. Bessemer, and it is declared that it will be kept perfectly free from rolling during the passage across the Channel, and passengers it is expected, will not feel any more unpleasant sensation than they would in going up or down the Thames. The ship will be supplied with two very large life rafts on the plan patented by Mr. Christie, and she will be steered and her capstans, &c., will be worked by hydraulic machinery. She was designed by Mr. E. J. Reed, C. B., M. P. —*Times.*